AGE AND ORIGIN OF THE McMURRAY FORMATION

G· B· MELLON

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The Department of Geology, University of Alberta, considers that this thesis represents a contribution to the science of geology of considerable merit. The findings expressed in this thesis are not necessarily the views of the members of the Department of Geology.

ABSTRACT

Samples from an almost complete core of the basal part of the Clearwater formation and the McMurray formation were examined for their microfaunal content. Twenty-one species of foraminifera and one species of ostracoda are reported from the Clearwater formation, along with seven species of foraminifera from the upper part of the McMurray formation. Most of the foraminifera are described and figured.

The upper part of the McMurray formation is demonstrated to be marine, deposited in a shallow, brackish-water lagoon, and is transitional from the lower, presumably continental beds of the formation, upwards into the marine, epineritic shales of the Clearwater formation. Using foraminifera, the base of the Clearwater formation and the upper part of the McMurray formation are correlative with the upper part of the Loon River formation, and the lower part of the Moosebar formation.

Examination of heavy mineral residues from the McMurray formation shows two distinct suites are present: first-cycle minerals derived from an igneous-metamorphic terrane, and second-cycle tourmaline and zircon derived from pre-existing sediments. Unstable and metastable minerals, such as amphiboles and pyroxenes, are absent or very rare.

Conclusions reached are that the upper part, and

possibly all, of the McMurray formation is middle Albian in age, deposited contemporaneously with and marginal to the westward-lying Loon River sea. Source of the sediments is to the east, derived in part from Precambrian igneous and metamorphic rocks, and in part from pre-existing sediments.

UNIVERSITY OF ALBERTA

AGE AND ORIGIN OF THE McMURRAY FORMATION

A DISSERTATION

Submitted to the School of Graduate Studies in partial fulfilment of the requirements for the degree of Master of Science.

Faculty of Arts & Science
Department of Geology

by

George Barry Mellon

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PLATES, FIGURES, TABLES

CHAPTER ONE

Introduction

Preliminary examination of the contents of an almost complete core of the McMurray formation and the basal part of the Clearwater formation justified further research, which took the form of micropalaeontological and petrological investigations, with the two-fold object of assigning a precise age to the type section of the McMurray formation, and ascertaining the nature of the source area.

Previous work

The bituminous nature of the McMurray formation is well known, and the nature of the bitumen, methods of extracting it from the sands, and the areal extent and amount of bitumen present have been thoroughly and ably investigated by members of the Research Council of Alberta, the Dominion Government, and various private companies. As a result, no attempt will be made here to review literature pertaining to the economic aspects of the formation, nor will theories regarding the source and age of the bitumen be discussed. For a complete and precise summary of the various general geological aspects of the McMurray formation, the reader is referred to the "Proceedings, Athabasca Oil Sands Conference", published by the government of Alberta in 1951.

No detailed accounts of the geology of the outcrop area of the McMurray formation have been published, although several reconnaissance surveys have been made: by Bell in 1884, McConnell in 1893, and McLearn in 1917, but only the very general features of the McMurray formation are noted in these reports.

Wickenden in 1947 redid part of the geology along the lower Athabasca River in considerable detail, but his study included only those strata down to the top of the Clearwater formation.

Reports of several oil companies which have carried on rather extensive surface and subsurface work in the outcrop area of the McMurray formation are not available to the public at the present time.

Material used and technical procedure

The material used in obtaining the information presented in this thesis was obtained from three sources: (1) The core of the Socony-Vacuum Oil Sands Well #27, location Sec. 27-91-10 W4, Alberta. (Core recovery was 188 feet out of a total of 223 feet of core (80% recovery), and the Socony-Vacuum Company took a further 54 feet of the core for samples, hence leaving a final total of 134 feet (60% of the core) for the Research Council. However, as core loss and company samples were well distributed throughout the whole core, the core was essentially complete for the purpose of this study.)

(2) The core of the Athabasca Oilsand Project Well #77 location Sec. 30-94-11 W4, Alberta.

(3) Spot samples taken by the writer along the Athabasca River in May, 1954.

Procedure used in the preparation of the microfaunal samples.

Shale samples of the McMurray and Clearwater formations were slaked in water and run through a series of sieves. Only the material retained on the size 80 and 100 mesh screens was carefully examined and picked, as it was found that the finer material rarely contained any new elements. Although the shales slaked almost immediately, the presence of any bituminous sand laminae in the original shale sample made picking an extremely arduous task. Therefore, the samples were not taken at any definite intervals from the Socony-Vacuum core, but were chosen instead as spot samples from the non-bituminous shale breaks.

Procedure used in the preparation of the petrological samples.

Petrological samples of the McMurray sands had to have the bitumen content removed before any further work could be done. Refluxing the sand in a mixture of 90% benzene and 10% methanol for 8 or 10 hours proved very satisfactory for this purpose, but benzene alone was not satisfactory.

The sand was then screened, and the material retained between the size 100 and 200 mesh screens was kept for heavy mineral analysis. About 10 to 15 grams of this sand was put in a separating flask and thoroughly mixed with tetrabromoethane, sp.g. 2.96. The heavy minerals sank to the bottom of the flask and were siphoned off, dried, and mounted in "~~Aerochlor~~ Aroclor", index 1.66. The light fraction of the sand was also drained and mounted in Canada Balsa~~l~~m, index 1.54.

Acknowledgments

The writer wishes to acknowledge financial help in the form of the Shell Oil Graduate Fellowship which he held during the academic year 1954-55.

The writer also acknowledges the help of the Research Council of Alberta which provided him with the core of the Socony-Vacuum well, and, by paying ~~for~~ his expenses, made it possible for him to spend ten days examining the type section area of the McMurray formation along the Athabasca River.

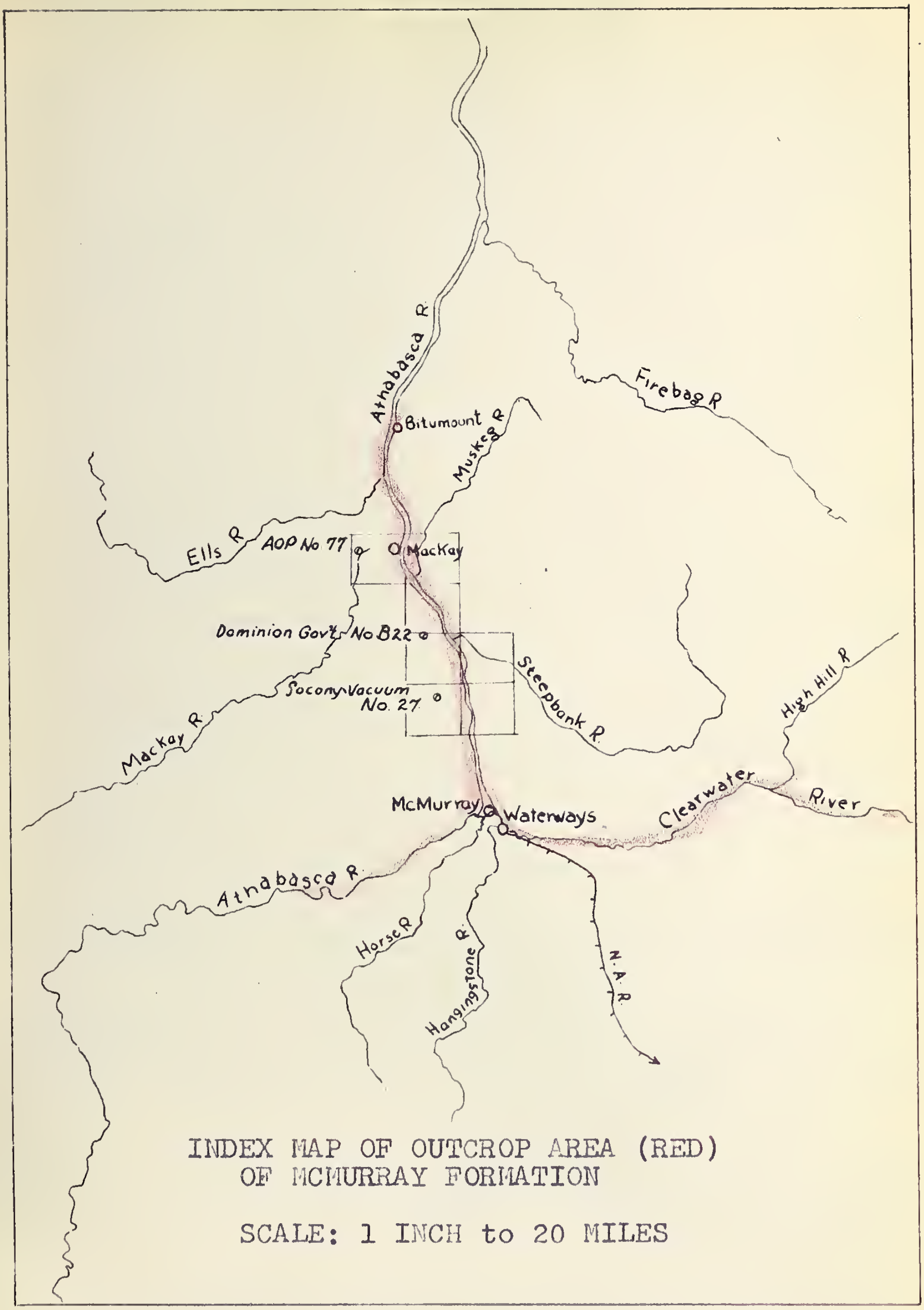
The writer would like to point out the foresight of Dr. K.A. Clark, retired head of the Department of Mining Engineering, who obtained the core of the Socony-Vacuum well for the Research Council.

Thanks are owing to Mr. George Collins, Research Council geologist, who showed the writer the various sections along the Athabasca River, and whose knowledge

of the McMurray formation in that area has been a definite help in the preparation of this thesis.

Mr. H. Bentham, formerly the Athabasca Oilsands Project geologist in McMurray, generously allowed the writer to sample one of the A.O.P. cores.

Finally, the writer wishes to thank Dr. C.R. Stelck and Mr. J.H. Wall for their help and criticism in preparing the palaeontological part of the thesis, and Dr. C.P. Gravenor for his help and criticism in preparing the petrological part.



INDEX MAP OF OUTCROP AREA (RED)
OF MCMURRAY FORMATION

SCALE: 1 INCH to 20 MILES

FIGURE 1

CHAPTER TWO

The McMurray formation - general statement.

While previous reconnaissance surveys were made along the lower Athabasca River, McLearn's (1917) report was the first to use the formational name "McMurray," and, for this reason, his section along the river is important, even although only the briefest summary was published. Wickenden (1949) redid in some detail part of the section along the lower Athabasca River, but only that part which includes the strata down to the top of the Clearwater formation, and, as a result, no literature is available which treats either the Clearwater or McMurray formations in other than a very general way.

Stratigraphic section along the lower Athabasca River from Joli Fou Rapids to Bitumount.

Joli Fou fm. 40 ft. dark grey, non-calcareous shale.

Grand Rapids fm. 360 ft. sandstone and siltstone, some minor shale.

Clearwater fm. 275 ft. soft, grey or black marine shale, minor glauconitic sandstone beds.

McMurray fm. 200 (approx.) ft. massive to thick, cross-bedded, bitumen-impregnated sands, becoming shaley and thinner-bedded towards the top.

unconformity

Waterways fm. fossiliferous limestone and shaley limestone.

The McMurray formation outcrops along the lower Athabasca River and its tributaries from Boiler Rapids,

west of the town of McMurray, to several miles north of the refinery at Bitumount, and the exposures along the Athabasca River itself may be taken as the type section of the formation.

The formation rests unconformably upon the Waterways limestone, which Warren and Stelck (1950) consider to be early Upper Devonian in age, while the upper limit is set at the base of a green, glauconitic sandstone, above which the Lemuroceras fauna of the Clearwater shale appears (McLearn, 1917). This contact between the Clearwater and McMurray formations marks an abrupt change in depositional environment, but, as will be discussed later, there is no time break at the boundary of the two formations, nor is there any valid evidence for postulating a hiatus within the McMurray formation itself.

Where seen along the Athabasca River, the McMurray formation varies from about 150 to 200 feet in thickness, although data from numerous boreholes on both sides of the river show that the formation varies considerably in thickness in very short distances owing to the very uneven surface of the underlying Waterways limestone. The formation consists of beds of unconsolidated to very friable quartz sand, held together mainly by their well-known bitumen content. The lower part of the formation is massive to thick-bedded, and cross-bedded on a very large scale, while the upper 50 feet or so tends to be

thinner-bedded, with the intercalation of silt and clay lenses and laminae between and within the sand beds. Conglomerate is rare, either at the base or within the formation, but the basal beds may become a coarse-grained grit, grading upwards into finer-grained sands. Borehole and outcrop data show that usually several feet of residual clay and sand separates the McMurray formation proper from the underlying limestone. The petrology of the formation, particularly the heavy mineral content, is discussed in Chapter Four.

<u>Age and correlation of the McMurray formation.</u>

Before discussing the age of the McMurray formation, the age of the overlying Clearwater formation and its correlatives in other parts of Western Canada must be reviewed. The megafauna of the Clearwater shale has been described by McLearn (1933) as consisting of the ammonoid genera <u>Beudanticeras</u> and <u>Lemuroceras</u> (then thought to be <u>Deshayesites</u>), the pelecypod <u>Inoceramus dowlingi</u>, and other pelecypods and rare gastropods. This <u>Lemuroceras</u> fauna was stated to range throughout the entire formation, no attempt having been made to distinguish more precise faunal horizons.

According to Stelck (1950, p.15), in the Pine River area of B ritish Columbia, <u>Lemuroceras</u> ranges from the lower part of the Gates formation down into the upper

part of the Moosebar formation, and in the lower Peace River area of Alberta, Lemuroceras ranges from the basal member of the Peace River formation down into the upper part of the Loon River formation. Stelck further recognizes that the ammonite Cleoniceras cf. subbaylei Spath occurs below Lemuroceras in the Loon River formation on the Peace River, but Cleoniceras has not, to the writer's knowledge, been collected from the Moosebar or Clearwater formations.

L.J. Martin (1954) described a microfauna from the upper 190 feet of the type section of the Clearwater formation along the Athabasca River. As the Clearwater formation is estimated to be 275 feet thick at the type section, Martin's fauna was therefore obtained from the upper two-thirds of the formation. This fauna contained the diagnostic species Haplophragmoides gigas var. minor Nauss and enabled Martin to correlate with the Cummings member fauna of the subsurface Mannville formation described by Nauss (1947) from the Vermilion area of Alberta.

In the many years the McMurray formation has undergone investigation, surprisingly few fossils have been found in it. Russell (1932) described a small fauna (referred to hereafter as the Lioplacodes bituminis fauna) from near the top of the formation on Hangingstone River, and which contained the following species:

<u>Unio (Elliptio) biornatus</u>
<u>Murraia naiadiformis</u>
<u>Viviparus murraiensis</u>
<u>Lioplacodes bituminis</u>
<u>Goniobasis multicarinata</u>
<u>Melania multorbis</u>
<u>Melampus athabascensis</u>

Russell stated that the fauna was "predominantly composed of non-marine genera, and reckoning by individuals, is overwhelmingly of fresh-water habitat. However, there are several forms present suggesting brackish water or even marine conditions .... It is suggested, on the basis of the molluscan fauna, and subject to revision in the light of field evidence, that the McMurray formation was developed under estuarine or near estuarine conditions." The fauna, although consisting entirely of new species not found elsewhere, was provisionally correlated with the Blairmore formation (presumably the lower part, see McLearn, 1932, p.170). Russell added that "if the two formations are not quite contemporary, the McMurray is most likely the older."

Russell noted in his paper of 1932 that "a small marine faunule near the top of the formation is reserved for description by Dr. F.H. McLearn." This fauna had been previously mentioned by McLearn (1931) as occurring in the transition beds between the Clearwater and McMurray formations above the <u>Lioplacodes bituminis</u> fauna later described by Russell. He stated "it is a brackish or a non-marine fauna and includes "<u>Astarte</u>" <u>natosini</u>, n.sp.",

however, the type figure and description of this species included in this same paper are quite sketchy. McLearn (1945) further explained the "A." natosini fauna as consisting of some small pelecypods and rare gastropods occurring at the base of the Luscar formation in the Mountain Park area of the Alberta foothills, and at the top of the McMurray formation on the Athabasca River. Only "A." natosini itself was figured in the accompanying plates (along with three forms from the Lioplacodes bituminis fauna) but the other "small pelecypods and rare gastropods" of the "A." natosini fauna from the Luscar formation have apparently yet to be figured or described.

Hume (1947, p.304) mentions that six genera of foraminifera and some small pelecypods were obtained from the core of a government boring of the McMurray formation in the Mildred-Ruth Lakes area (Hole No. B22, location, section 32-92-10 W4). This fauna occurs in a 17 foot band of dark marine shale which is overlain by 56 feet of bituminous sands and clays. These forms, which seem to occur at least 56 feet below the top of the McMurray formation (the contact with the overlying Clearwater formation has been eroded) have unfortunately not been figured.

Well-preserved tree trunks and wood (Gorden, 1932) have been found in the McMurray formation, but no

representative flora has yet been reported. The writer has obtained _Ginkgo_ and a few other plant fragments from a small outcrop on the Athabasca River between Fort MacKay and Bitumount. The precise position of this outcrop in the McMurray formation is not known, but is certainly within the lower half.

The writer has obtained a fauna from the Socony-Vacuum Oil Sands Well #27 which throws additional light on the age and depositional environment of the McMurray formation. Three distinct faunal zones are recognized from this core and the two marine faunas are figured and described.

(1) The "basal Clearwater shale zone" is found at a depth of 73 to 92 feet and includes the following species:

PELECYPODA
**_Yoldia kissoumi_ McLearn

OSTRACODA
**_Cytheridea_ (sensu lato) sp.

FORAMINIFERA
Ammobaculites humei Nauss
**_Ammodiscus_ sp.
**_Bathysiphon_ sp.
Haplophragmoides gigas var. _minor_ Nauss
Haplophragmoides M1-A
**_Leptodermella?_ sp.
Miliammina M1-A
Tritaxia M1-A
Verneuilinoides? M7-A

Discorbis M1-A
Eponides M1-A
Globulina lacrima Reuss
Lenticulina M1-A

Marginulina M1-A
Marginulina M1-B
Nodosaria obscura Reuss
Pseudoglandulina M1-A
Saracenaria M1-A
Saracenaria M1-E
Saracenaria M1-F

** signifies that the form is not described or figured here.

The glauconite sand found at a depth of 92 to 101 feet is apparently barren in the Socony well.

(2) The "marine McMurray zone" is found at a depth of 101 to 117 feet and includes the following species:

FORAMINIFERA
**_Ammodiscus_ sp.
Haplophragmoides M6-B
Haplophragmoides M8-C
Miliammina M8-B
Trochammina M7-A
**_Trochammina?_ sp.
Verneuilinoides? M7-A

** signifies that the form is not described or figured.

This same fauna, excepting _Ammodiscus_ sp. and _Trochammina?_ sp., was also found in the core of the A.O.P. Well #77 from a depth of 55-60 to 75-80 feet, immediately underlying shaley, glauconitic sand.

(3) The "non-marine McMurray zone" is found at a depth of 117 to 293 feet, and includes the following elements:

a) occasional ostracodes, too poorly preserved to be identified with any certainty.

b) rare "spores" , along with much finely ground-up cuticle and carbonaceous material.

c) unidentified arenaceous objects (not foraminifera, but apparently organic).

The basal Clearwater fauna is important in that it extends Martin's (1954) fauna from the central part of the formation down to the base. The basal Clearwater fauna further enables correlation with the Peace and Pine Rivers sections, and throws new light on the so-called "ostracode zone" of Central and Southern Alberta.

Several calcareous species of foraminifera found by Stelck (1950) in the lower part of the Moosebar formation in the Pine River area of British Columbia are present in the Clearwater formation, but the arenaceous forms from the two horizons are dissimilar. In view of the rather poor preservation of the Moosebar fauna, however, the writer hesitates at equating the base of the Moosebar formation with that of the Clearwater.

The Loon River formation, where it outcrops along the lower Peace River from below the town of Peace River to Vermilion Rapids, has yielded several microfaunal suites. The upper 80 feet of the Loon River shales plus the lower 60 feet of the overlying basal member of the Peace River formation has yielded an excellent microfauna (Wickenden, 1949), and enough of the species are also found in the basal Clearwater formation to permit correlation.

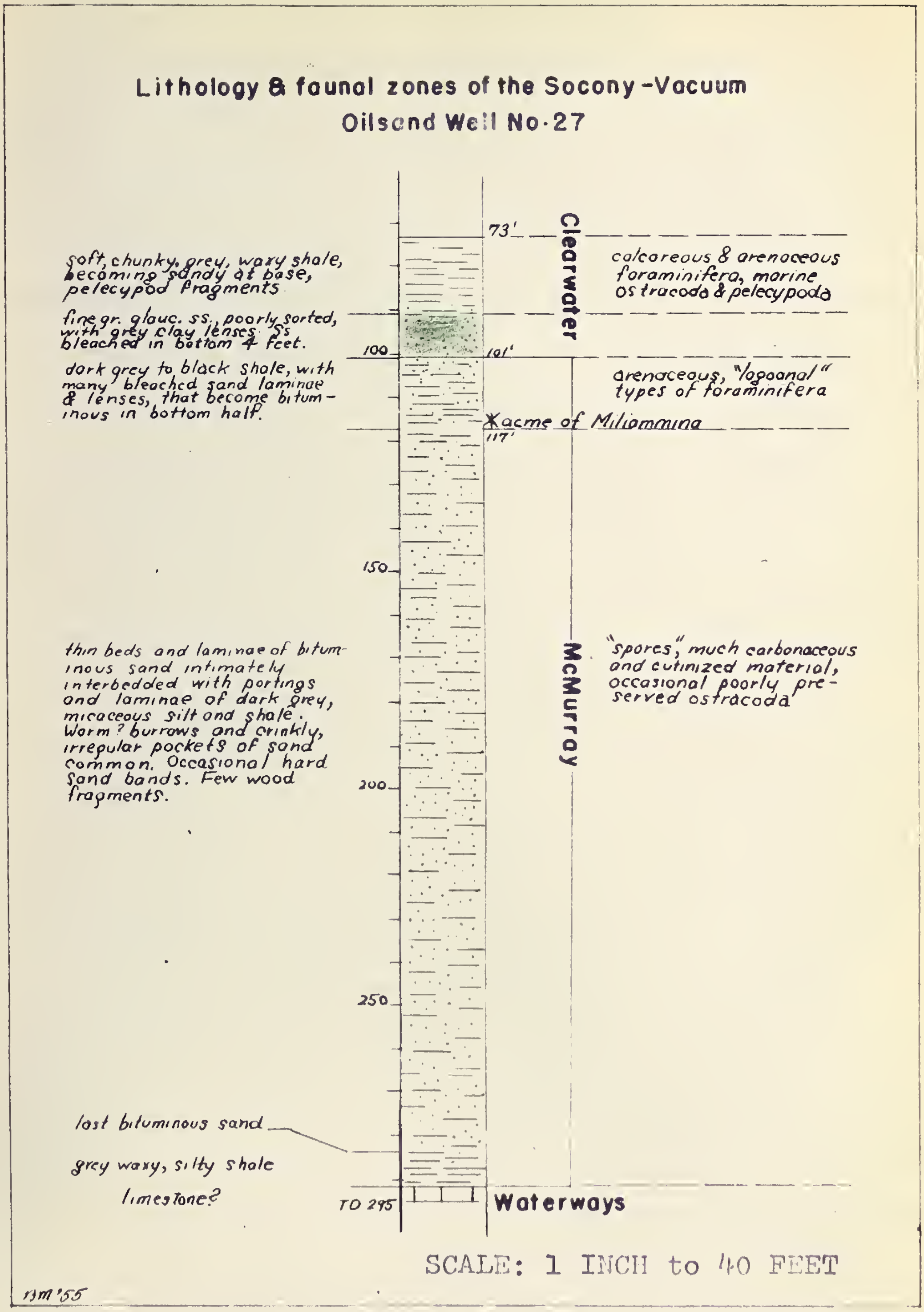

Lithology & faunal zones of the Socony-Vacuum
Oilsand Well No·27
soft, chunky, grey, waxy shale, becoming sandy at base, pelecypod fragments
fine gr. glauc. ss., poorly sorted, with grey clay lenses. Ss bleached in bottom 4 feet.
dark grey to black shale, with many bleached sand laminae & lenses, that become bituminous in bottom half.
thin beds and laminae of bituminous sand intimately interbedded with partings and laminae of dark grey, micaceous silt and shale. Worm? burrows and crinkly, irregular pockets of sand common. Occasional hard sand bands. Few wood fragments.
last bituminous sand
grey waxy, silty shale
limestone?
73'
100
101'
117'
150
200
250
TO 295
Clearwater
McMurray
Waterways
calcareous & arenaceous foraminifera, marine ostracoda & pelecypoda
arenaceous, "lagoonal" types of foraminifera
acme of Miliammina
"spores", much carbonaceous and cutinized material, occasional poorly preserved ostracoda
SCALE: 1 INCH to 40 FEET
RJM '55

FIGURE 2

A microfauna described by F.H. Trollope (1951) and a microflora described by W.A. Norris (1951) from outcrop sections of the Loon River formation, stratigraphically below Wickenden's (1949) sections, have not yet been recognized elsewhere. Trollope's and Norris' suites are calibrated in part with the ammonite Cleoniceras cf. subbaylei, which, as already pointed out, occurs below Lemuroceras in the Loon River formation. The writer has also obtained an aberrant arenaceous microfauna from a core taken near the base of the Loon River formation in the Socony-Vacuum Buffalo Head Hills well (location, lsd. 8-6-103-16 W5, Northwest Alberta). This "Buffalo Head Hills fauna" is distinct from microfaunas found in the Clearwater McMurray sequence and outcrop sections of the Loon River formation along the Peace River.

The Clearwater shale overlies the McMurray formation conformably and there is no break in deposition at the boundary of the two formations. The sharp break in the microfaunal content of the two formations is ascribed to change in depositional environment, and the two foraminiferal assemblages are thought to be essentially contemporary. The fact that Verneuilinoides? M7-A and Miliammina are found in both the upper part of the McMurray formation and the overlying Clearwater formation establishes this.

The Clearwater foraminifera are calibrated against the ammonite Lemuroceras, which is basal middle Albian

in age at the earliest, and, therefore, it follows that the upper part of the McMurray formation, including the Lioplacodes bituminis fauna, is also middle Albian in age or just slightly older. No diagnostic fossils have yet been figured from the lower non-marine part of the McMurray formation, but the writer suggests that these strata are the same age as some of the lower beds of the Loon River formation, i.e. equal in whole or in part to the Cleoniceras cf. subbaylei zone which is late lower Albian in age. Although this argument is based on the assumption that there is no apparent hiatus within the McMurray formation, there is yet no valid evidence for placing the McMurray formation in other than the Albian stage.

The relationship of the Clearwater-McMurray sequence to the mainly non-marine Blairmore formation and equivalent formations in the Central Alberta foothills is much more difficult to define. The flora from the lower part of the Blairmore formation (equals Luscar flora) has been dated Aptian by Bell (1946), and, as the Lemuroceras fauna of the Clearwater formation was also originally dated Aptian by McLearn (1932, 1933), it was assumed at the time that the Blairmore-Luscar sediments were deposited as an alluvial plain marginal to the boreal Clearwater-Loon River sea.

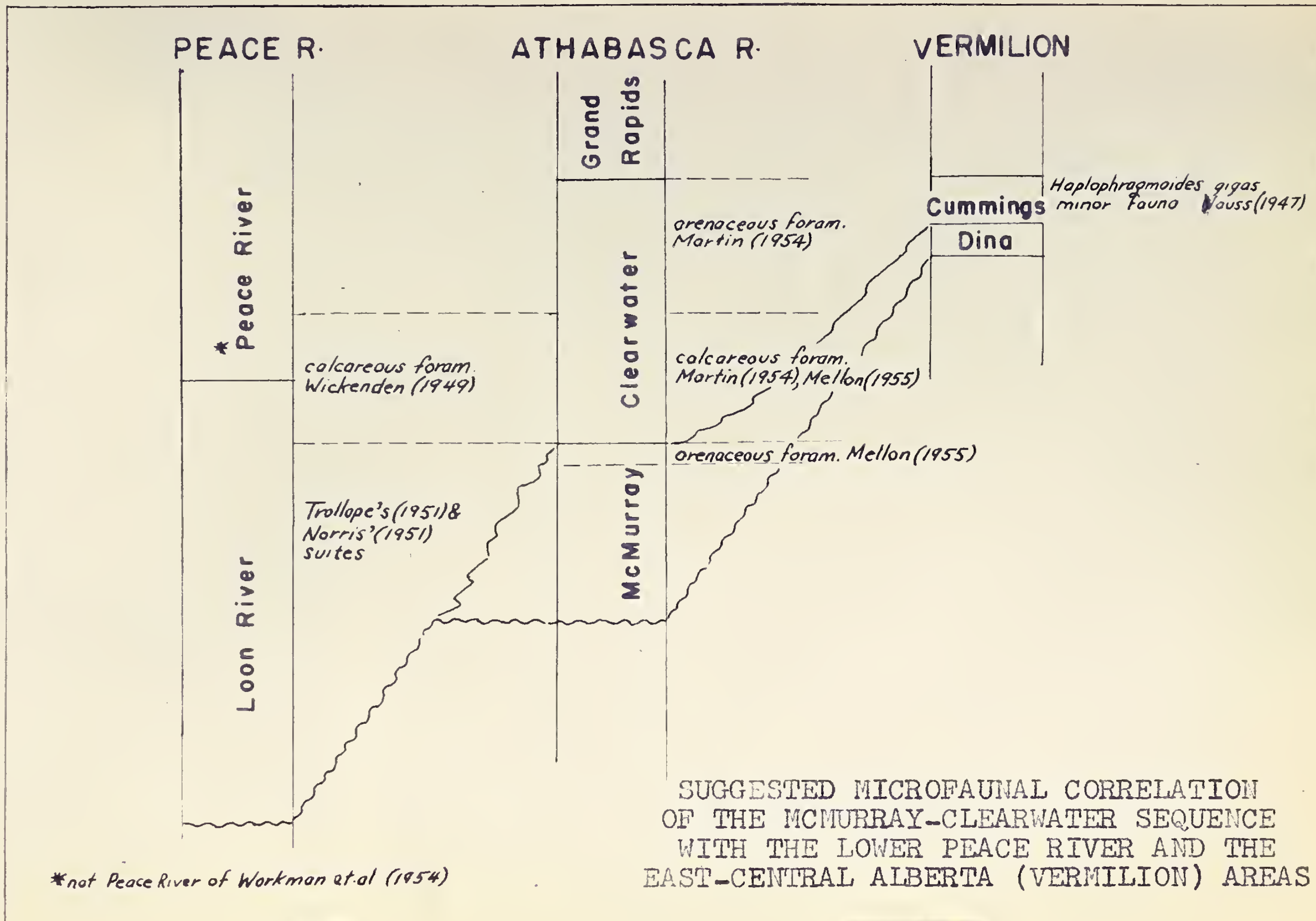
Miss D.M. Loranger (1951) described a microfauna

from the subsurface "Blairmore" sediments of Central and Southern Alberta and outcrop sections of the lower parts of the Blairmore and Luscar formations in the foothills. She stated that "the zone varies from 20-70 feet in thickness and is dominated by Metacypris persulcata Peck and associated ostracodes", and that "the sediments enclosing the metacyprids commonly contain Unio hamili which is considered irrefutable evidence for Aptian age in Western Canada."

Badgley (1952) published a paper which is essentially a combined electrolog and lithologic correlation of the Lower Cretaceous strata of widely spaced wells in Central and Northern Alberta, and in this paper he also changed the name of the Metacypris persulcata zone to the Metacypris angularis zone. The basic anomaly in his correlation is well demonstrated in his "Stratigraphic Cross-section of the Lower Cretaceous Series from Ram River to Pouce Coupe". He figures the Metacypris zone as occurring near the base of the Blairmore formation where it outcrops in the Ram River area in the foothills, and carries it some 95 miles to the nearest well, Imperial Battle Lake #1, where the zone is shown occurring at the base of the so-called "Clearwater" formation. Between Battle Lake #1 and Pouce Coupe, the zone is also shown occurring near the base of the type section of the Clearwater formation on the Athabasca River, and finally in the Bluesky formation in

the subsurface of the Peace River area, above beds correlated with the Gething formation of the Peace River foothills. In other words, the "ostracode zone" starts out near the "Aptian" base of the Blairmore formation and, amongst other things, ends up at the base of the type section of the Clearwater formation which is middle Albian in age!

Marine ostracoda obtained by the writer from the base of the Clearwater formation in the Socony-Vacuum well in the type section area are not present in the metacyprid assemblage figured by Loranger, nor is there any evidence that the ostracodes obtained from the lower part of the McMurray formation in the same well are similar to those of the metacyprid assemblage. It should be further noted here that Nauss (1945, 1947) makes no mention of ostracodes occurring in the type section of the Mannville formation (not Badgley's Mannville Group) in the Northwest Mannville Well #1 in the Vermilion area of East-Central Alberta. Instead, Nauss (1947) figures the Haplophragmoides gigas var. minor fauna from the Cummings member of the lower part of the Mannville formation which correlates with the type section of the Clearwater formation. The writer would like to call attention to the fact that ostracodes occur in strata ranging in age from Ordovician to Recent, and, therefore, the possibility that there is more than one "ostracode zone" in the Lower Cretaceous of Western Canada should be considered.



SUGGESTED MICROFAUNAL CORRELATION
OF THE MCMURRAY-CLEARWATER SEQUENCE
WITH THE LOWER PEACE RIVER AND THE
EAST-CENTRAL ALBERTA (VERMILION) AREAS

FIGURE 3

As the Loon River-Clearwater sea entered Alberta from the north, it can be safely assumed that the basal onlap sand (Bluesky formation or the Glauconite sand at the base of the Clearwater formation) becomes slightly younger as it is traced progressively southward. If the Bluesky and the base of the Clearwater formation are the northern correlatives of the Metacypris zone from the Blairmore and Luscar formations, then the metacyprid biofacies would have to transgress downwards from strata of middle Albian age to those of Aptian age. This would be a transgression directly opposite to that of the lithofacies, which is highly improbable. Rejecting such a contention, one must arrive at the conclusion that the invading Albian sea advanced southward over the eroded surface of the Blairmore (Metacypris) sediments. The writer knows of no case where the metacyprid fauna interfingers with the true marine Clearwater fauna; where the two are present together in the same well (Bear Villa, Majeau Lake among others), the Clearwater foraminifera always overly the metacyprids.

The term McMurray as used by many petroleum geologists means any sand developed at the base of the Cretaceous sequence in Central and Northern Alberta and implies a correlation with the McMurray formation of type section area, A review of the palaeontological evidence suggests that the formational names Grand Rapids, Clearwater, and McMurray should be restricted to the type section area along the

lower Athabasca and its tributaries, and that Nauss' term Mannville represents a true formation in East-Central Alberta, separate from the Blairmore formation.

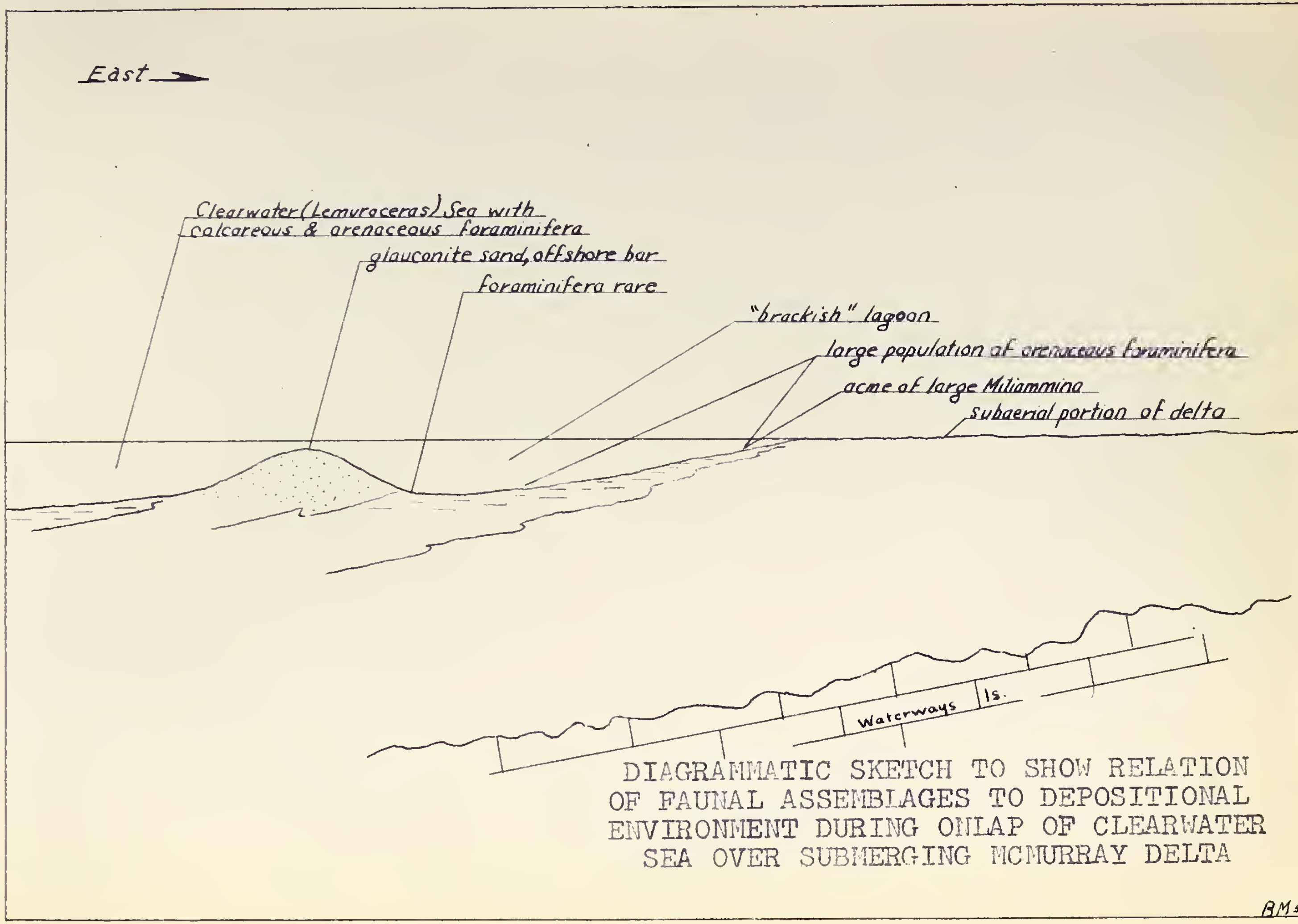
Depositional Environment

The distribution of the foraminifera within the core of the Socony-Vacuum Oil Sands Well #27, combined with certain lithologic and sedimentary features, permits reconstruction to a certain degree of the depositional environment of the McMurray formation. It should be emphasized that the following remarks are not intended to be dogmatic, but rather to express what seems to be the most reasonable interpretation of data obtained mainly from one well.

F.B. Phleger's (1954, p.584) detailed work on the foraminiferal assemblages of the Mississippi Sound area has been the guide in interpreting the two foraminiferal suites of the Socony well. Phleger divides his faunas into four geographic and ecologic facies, but the main distinction is between an open-gulf facies of calcareous foraminifera, and a sound or "lagoonal" facies of arenaceous foraminifera, separated from each other by a barrier of low offshore islands. The waters of the open gulf are thus prevented from invading the less saline water of the Mississippi Sound by both the barrier of offshore islands and the high run-off of fresh water from the adjoining mainland.

The foraminiferal assemblage from the upper part of the McMurray formation in both the Socony and A.O.P. wells is very similar to the Recent assemblage found by Phleger in marshes adjacent to the mainland. _Trochammina comprimata_ Cushman and Bronnimann and _Miliammina fusca_ Brady, both abundant in the Mississippi marshes, have their counterparts in the McMurray formation in _Trochammina M7-A_ and _Miliammina M8-B_. The partly calcareous fauna from the basal Clearwater shales of the Socony well is thought to be analagous to Phleger's open-gulf fauna.

The glauconite sand is interpreted as forming an offshore bar, produced by the winnowing action of the Clearwater sea. This barrier prevented the normal saline waters of the onlapping Clearwater sea and its fauna from contaminating the _Miliammina_-dominated assemblage living in shallow, brackish water adjacent to the so-called McMurray "delta". The significance of the glauconite itself in relation to environment is difficult to determine. Galliher's (1935) study of the glauconite now forming in Monterey Bay requires biotite for the formation of the mineral, but while muscovite is common in the McMurray formation, biotite is very rare. The stagnant conditions that supposedly aid in the formation of glauconite are hinted at where the several feet of black shale underlying the glauconite sand in both the Socony and A.O.P. wells does not contain foraminifera.



DIAGRAMMATIC SKETCH TO SHOW RELATION
OF FAUNAL ASSEMBLAGES TO DEPOSITIONAL
ENVIRONMENT DURING ONLAP OF CLEARWATER
SEA OVER SUBMERGING MCMURRAY DELTA

FIGURE 4

The main body of the McMurray formation underlying the upper marine shales has generally been considered a deltaic deposit. The massive, lenticular, cross-bedded nature of the bituminous sands where they are exposed along the Athabasca River seems to favour such an environment, but certainly does not prove it.

That part of the formation referred to as the "non-marine" McMurray in the Socony well is somewhat different than the exposures along the river, a few miles to the east. In this well, no thick, homogenous beds of sand are present, but the whole of the formation underlying the marine shales consists of very thin beds or laminae of fine to very fine sand, intimately interbedded with equally thin beds of grey, carbonaceous silt and shale. Sorting on a very small scale is quite conspicuous; that is, laminae and small millimeter-thick partings of sand, each a sedimentary unit in its own right, occur within the shalier portions of the core so that mechanical analyses would be of no interpretive value except to give the relative sand to silt-clay proportions within that portion of the core actually sampled. Numerous pockets and tubes of sand, interpreted as worm burrows, cut across bedding planes, and it would seem that a good part of the formation in the core has passed through the intestinal tracts of burrowing organisms.

The non-bituminous silt and clay sections contain wood fragments, much fine carbonaceous material and tiny

pieces of plant cuticle, but, apart from a few logs and plant fragments, no representative flora has yet been reported from the formation. This suggests that the actual "delta" itself was not suitable to the growth of plant life in any quantity, and what few leaf and wood fragments have been found were transported to the site of deposition from the hinterland to the east.

To sum up, it has not been proven or disproven that the bituminous sands and clays of the formation actually interfinger with definitely marine strata to the west. There is a transitional environment at the top of the formation in the Socony and A.O.P. wells, but there is no evidence in either well that the part of the formation underlying the foraminifera-bearing beds was deposited under marine conditions. The lack of marine fossils and the presence of large scale cross-bedding and lenticular nature of the beds argue for a deltaic type of deposition for the lower, larger part of the McMurray formation in the type section area.

CHAPTER THREE

Description of species.

The species described and figured here were obtained from the Clearwater and McMurray formations in the core of the Socony-Vacuum Oil Sands Well #27, location: section 27-91-10 W4, Alberta.

Species are arranged alphabetically by genera, instead of by families, in order to facilitate finding the descriptions when comparing them with the corresponding figures in Plates 1 and 2.

Terms used in describing the abundance of a particular species are as follows:

"abundant" - more than a hundred individuals of that species present in a particular sample.

"common" - 21 to 100 specimens present.

"occasional" - 6 to 20 specimens present.

"rare" - 5 or less specimens present.

Table 1 shows the exact number of individuals per species present in each sample, excepting for the various species of Haplophragmoides in the Clearwater samples. Rather poor preservation of the specimens prevented making population counts of the particular species of that genus. The writer would further like to note that more than two species of Haplophragmoides are present in the Clearwater samples (see Martin, 1954), but they have not all been distinguished in this thesis.

Phylum PROTOZOA

Order FORAMINIFERA

Genus AMMOBACULITES Cushman, 1910

<u>Ammobaculites humei</u> Nauss

(Plate 1, fig. 18)

<u>Ammobaculites humei</u> Nauss, 1947, Jour. Pal., Vol. 21, No. 4: p. 333, pl. 48, fig. 1.

Test usually somewhat flattened and distorted in fossilization, early portion tightly coiled and comprised of five or six equal chambers, later portion consisting of up to six chambers in straight uniserial arrangement; chambers gradually increasing in size, the ultimate chamber tending to be pyriform; sutures distinct, depressed, at right angles to the long axis of the test; wall coarsely arenaceous, of angular quartz grains up to .08 mm. but averaging about .04 mm., with a small amount of cement giving a rough finish to the test; aperture a terminal, central opening; colour white.

Length of hypotype: .8 mm.

Hypotype locality: Socony-Vacuum Oil Sands Well #27, in section 27-91-10-W4, Alberta, at a depth of 73-81 ft., 28-20 ft. above the base of the Clearwater formation.

Hypotype: Univ. of Alberta Pal. Type Coll.

Horizon: This species occurs occasionally to abundantly in the basal shales of the Clearwater formation in the Socony-Vaccum Oil Sands Well #27, from the top of the glauconite sand at 92 ft. to the top of the core at 73 ft.

Remarks: Considerable variation exists in this species regarding the size of the uncoiled portion and the number of chambers in the uncoiled portion, which varies from two to six.

Comparison of the basal Clearwater form with some of Nauss' specimens from the Cummings member shows that the latter differ mainly in having a large amount of siliceous cement, imparting a smooth exterior finish to the test in spite of the coarse grain size.

Genus DISCORBIS Lamarck, 1804.

Discorbis M1-A

(Plate 2, fig.9, 10,11)

Test small, trochoid in a left or right hand spiral, dorsal side convex, ventral side tending to be concave and umbilicate, extra material from chambers partially or completely covering umbilicus; test of two whorls, of a spherical proloculus and about eleven subsequent chambers; chambers distinct, gradually expanding, but not inflated, all chambers visible from dorsal side, only those of the last formed whorl from the ventral side; sutures oblique, flush, translucent; wall calcareous, finely perforate, very fragile; aperture a slit at the anterior ventral margin of the last formed chamber; colour light brown.

Maximum diameter of hypotype: .27 mm.

Thickness of hypotype: .09 mm.

Hypotype locality: Socony-Vacuum Oil Sands Well #27,

in section 27-91-10W4, Alberta, at a depth of 73-81 ft., 28-20 ft. above the base of the Clearwater formation.
Hypotype: lost, replaced by unfigured paratype from the same location. Paratype in the Univ. of Alberta Pal. Type Coll.
Horizon: Rare in the basal shales of the Clearwater formation in the Socony-Vacuum Oil Sands Well #27, from the top of the glauconite sand at 92 ft. to the top of the core at 73 ft.
Remarks: This species is similar to Discorbis plana Heron-Allen and Earland, a Recent form, but differs from D. plana in being much smaller in size.

Discorbis M1-A is similar to Discorbis Z-7-56-A Martin from the central part of the Clearwater formation, type section.

Genus EPONIDES Montfort, 1808

Eponides M1-A

(Plate 2, fig. 12, 13, 14)

Test small, trochoid in a clockwise spiral, biconvex, tending to be globigerinoid; test with a very low spire, of two or three whorls of four chambers each and a proloculus; chambers increase suddenly in size at the end of each whorl, last four noticeably inflated and sub-globular, all chambers visible from dorsal side and usually four from ventral side; sutures distinct, oblique, those of last whorl depressed; umbilicus closed; aperture not readily evident, apparently as a narrow slit on inner margin of last-formed chamber;

wall calcareous, medium perforate, smooth and translucent; colour light brown.

Maximum diameter of hypotype: .27 mm.
Hypotype locality: Socony-Vacuum Oil Sands Well #27, in section 27-91-10 W4, Alberta, at a depth of 73-81 ft., 28-20 ft. above the base of the Clearwater formation.
Hypotype: Univ. of Alberta Pal. Type Coll.
Horizon: This species occurs occasionally in the basal shales of the Clearwater formation in the Socony-Vacuum Oil Sands Well #27, from the top of the glauconite sand at 92 ft. to the top of the core at 73 ft.
Remarks: This species is the second-most common calcareous form found in the Socony well. A certain amount of variation is present, particularly regarding the degree of inflation of the chambers of the last whorl. The form is referred to Eponides, rather than Globigerina, because it lacks the large opening into the umbilicus, and is light brown in colour, a feature supposedly typical of many of the Rotaliidae.

Eponides M1-A is identical with Eponides Z-7-54-A Martin from the central part of the Clearwater formation, type section. It is also apparently identical with Globigerina 20-81A Stelck from the lower part of the Moosebar formation, but poor preservation of Stelck's type makes precise identification uncertain.

Genus GLOBULINA d'Orbigny, 1839.

Globulina lacrima Reuss n. var.

(Plate 2, fig. 6)

for ref. see: Frizzell, 1954, Handbook of Cret. Foram., p.104.

Test small, tear shaped, circular in cross-section, generally of three or four chambers which extend back almost to the base; sides and base concave, never straight; sutures distinct, flush, seldom slightly depressed; wall fragile, smooth, calcareous, finely perforate; apertural end extended with radiate aperture and small apertural chamber; colour hyaline to white opaque.

Length of Hypotype: .31 mm.

Hypotype locality: Socony-Vacuum Oil Sands Well #27, in section 27-91-10 W4, Alberta, at a depth of 73-81 ft., 20-28 ft. above the base of the Clearwater formation.

Hypotype: Univ. of Alberta Pal. Type Coll.

Horizon: Rare to occasional in the basal shales of the Clearwater formation in the Socony-Vacuum Oil Sands Well #27, from the top of the glauconite sand at 92 ft. to the top of the core at 73 ft.

Remarks: This form is similar to Globulina lacrima var. lacrima Reuss described by Cushman from the Upper Cretaceous of Texas, except that the Texas form is larger and tends to have straight sides. The type material of Reuss from the Upper Cretaceous of Germany ranges in size from .75-1.0 mm.

in length, and is hence considerably larger than the basal Clearwater form.

The basal Clearwater form is identical to Globulina Z-7-56-A Martin from the central part of the Clearwater formation, type section; to Wickenden's Globulina sp. (1951, Plate 1A, fig. 27) from the upper part of the Loon River formation; and to Guttulina, 20-92A Stelck from the lower part of the Moosebar formation.

Genus HAPLOPHRAGMOIDES Cushman, 1910.

Haplophragmoides gigas var. minor Nauss

(Plate 1, fig. 10)

H. gigas var. minor Nauss,1947,Jour.Pal.,Vol.21,No.4: p.338,pl.49,fig.10.

Test of medium size, compressed, usually more or less flattened in fossilization, planispiral and completely involute; periphery sharply rounded, the thickest part of the test being about the umbilical margin; chambers gradually increasing in size, six to ten being visible in the ultimate whorl; sutures sigmoidal, distinct, very slightly depressed, marked in flattened specimens by a thickened ridge along the trace of the septal wall; wall finely arenaceous with much cement, giving a generally smooth or glazed exterior surface; aperture a low arch at the base of the terminal face.

Maximum diameter of hypotype: .5 mm.

Hypotype locality: Socony-Vacuum Oil Sands Well #27,

in section 27-91-10 W4, Alberta, at a depth of 73-81 ft., 28-20 ft. above the base of the Clearwater formation.
Hypotype: Univ. of Alberta Pal. Type Coll.
Horizon: Common in the basal shales of the Clearwater formation in the Socony-Vacuum Oil Sands Well #27, from the top of the glauconite sand at 92 ft. to the top of the core at 73 ft.
Remarks: This species is usually somewhat deformed in fossilization, making identification difficult. However the hypotype figured here seems to be almost identical with the figure of Nauss' holotype from the Cummings member of the Mannville formation.

On the other hand, the basal Clearwater specimens differ somewhat from Martin's specimens from the middle and upper part of the Clearwater formation, type section, in having siliceous instead of calcareous cement, and in having a more variable number of chambers in the last whorl.

Haplophragmoides M1-A

(Plate 1, fig. 15)

Adult test large, compressed, planispiral, almost involute, periphery rounded; chambers tending to be indistinct, their positions sometimes emphasized by crushing, seven to twelve chambers to a whorl, gradually increasing in size; sutures thickened, straight, flush, indistinct, their positions sometimes denoted by the trace of the intercameral walls; unbilicus shallow and usually filled, occasionally

showing a portion of the earlier whorl; wall arenaceous of fine clear quartz grains set in brownish cement, giving an even but not glazed exterior surface; aperture a low arch at the base of the terminal face; colour brownish.

Maximum diameter of hypotype: .7 mm.
Hypotype locality: Socony-Vacuum Oil Sands Well #27, in section 27-91-10 W4, Alberta, at a depth of 73-81 ft., 28-20 ft. above the base of the Clearwater formation.
Hypotype: Univ. of Alberta Pal. Type Coll.
Horizon: Common in the basal shales of the Clearwater formation in the Socony-Vacuum Oil Sands Well #27, from the top of the glauconite sand at 92 ft. to the top of the core at 73 ft.
Remarks: This species is distinguished mainly by its rather large size, and its tendency to become slightly evolute, showing a portion of the earlier coil. Other features are less distinct, and specimens tend to be more or less flattened.

Haplophragmoides M1-A is identical to Haplophragmoides Z-7-56-A Martin from the central and upper part of the Clearwater formation, type section, but is distinctly different from those species of Haplophragmoides described by Bahan (1951) from the Joli Fou and Grand Rapids formations.

Haplophragmoides M6-B

(Plate 1, fig. 7,8,9)

Test variable in size, planispiral, involute, somewhat

compressed, periphery rounded; chambers indistinct, six or seven in ultimate whorl, chambers sometimes made more distinct by crushing; sutures and umbilicus generally indistinct; wall coarsely arenaceous with large, clear, subangular quartz grains up to .1 mm. in diameter but averaging about .03 or .04 mm., set in a matrix of finer brownish material, often with small, black, carbonaceous fragments adhering to the outer surface; aperture an arch at the base of the terminal face.

Maximum diameter of hypotype: .5 mm.

Thickness of hypotype: .15 mm.

Maximum diameter of figured paratype: .6 mm.

Hypotype and figured paratype locality: Socony-Vacuum Oil Sands Well #27, in section 27-91-10 W4, Alberta, at a depth of 106-107 ft., 5-6 ft. below the top of the McMurray formation.

Hypotype and paratype: Univ. of Alberta Pal. Type Coll.

Horizon: Occasional in the upper marine shales of the McMurray formation. About 20 specimens were collected from the Socony-Vacuum Oil Sands Well #27 between a depth of 102-112 ft., and a similar number from the A.O.P. Well #77 between a depth of 55-60 to 75-80 ft.

Remarks: The coarseness of grain size of this form obscures any other diagnostic features that may be present.

Haplophragmoides M8-C

(Plate 1, fig. 11, 12)

Test of small to medium size, compressed, planispiral, involute; periphery rounded, the test being slightly thicker about the umbilical margin; umbilicus shallow but distinct; chambers of approximately equal size, rather indistinct but made more noticeable by flattening of the test, seven or eight in the ultimate whorl; sutures rather indistinct, slightly arcuate, their positions being emphasized by the strength of the intercameral walls; walls arenaceous, of fine, clear quartz grains set in a matrix of opaque, brownish material; aperture not observed; colour light brown.

Maximum diameter of hypotype: .5 mm.

Thickness of hypotype: .15 mm.

Hypotype locality: Socony-Vacuum Oil Sands Well #27, at a depth of 117 ft., 16 ft. below the top of the McMurray formation.

Hypotype: Univ. of Alberta Pal. Type Coll.

Horizon: Rare in the McMurray formation, occurring in the Socony-Vacuum Oil Sands Well #27 at a depth of 117 ft., and in the A.O.P. Well #77 at a depth of 75-80 ft.

Remarks: This form is figured here because it occurs, albeit rarely, with large numbers of *Miliammina M8-B*, and it seems to be distinct from *Haplophragmoides M6-B*, the other species of that genus that occurs in the McMurray formation.

Genus LENTICULINA Lamarck, 1804.

Lenticulina M1-A

(Plate 2, fig. 7, 8)

Adult test medium size, compressed, planispiral or slightly trochoid, thus showing the earlier chambers on one side; test of spherical proloculus with twelve or thirteen subsequent chambers, eight or nine in the last whorl; chambers distinct, gradually increasing in size, last one or two chambers very slightly inflated; sutures distinct, flush, arcuate, thickened, forming an incipient keel in the hypotype; wall calcareous, finely perforate, translucent; aperture radiate, a small round opening on the terminal face at the peripheral angle; colour white.

Maximum diameter of hypotype: .7 mm.
Hypotype locality: Socony-Vacuum Oil Sands Well #27, in section 27-91-10 W4, Alberta, at a depth of 73-81 ft., 28-20 ft. above the b ase of the Clearwater formation.
Hypotype: Univ. of Alberta Pal. Type Coll.
Horizon: Rare in the basal shales of the Clearwater formation in the Socony-Vacuum Oil Sands Well #27, from the top of the glauconite sand at 92 ft. to the top of the core at 73 ft.
Remarks: The basal Clearwater species figured here is somewhat similar to the "forme typique" of Cristellaria gaultina Berthelin from the Albian of France, except

that the French species has developed a distinct flange which is lacking on the Clearwater species. The latter is therefore suggested as a new species on the basis that it lacks a flange, and the adult test may tend to become slightly trochoid in the manner of those species described under the generic name "Darbyella".

Lenticulina M1-A is identical with Lenticulina Z-7-56-A Martin from the central part of the Clearwater formation, type section; and to Wickenden's Lenticulina sp. (1951, Plate 1A, fig. 13) from the upper part of the Loon River formation.

Genus MARGINULINA d'Orbigny, 1826.

Marginulina M1-A

(Plate 2, fig. 1, 2)

Adult test of medium size, robust, elongate; coiled portion compressed with five or six visible chambers, uncoiled portion of three chambers, becoming inflated and ovoid in cross-section; chambers distinct, particularly in uncoiled portion, last chamber tending to be slightly inflated; sutures distinct, becoming depressed in uncoiled portion; generally about twelve longitudinal costae running uninterrupted across the sutures from the last one or two chambers of the coiled portion to about one-quarter way up the terminal chamber, sometimes splaying out as they cross the last suture; wall calcareous, perforate, hyaline or opaque; aperture terminal, radiate, at the peripheral angle.

Length of Hypotype: .7 mm.

Hypotype locality: Socony-Vacuum Oil Sands Well #27, in section 27-91-10 W4, Alberta, at a depth of 73-81 ft., 28-20 ft. above the base of the Clearwater formation.

Hypotype: Univ. of Alberta Pal. T ype Coll.

Horizon: Generally rare in the basal shales of the Clearwater formation in the Socony-Vacuum Oil Sands Well #27, from the top of the glauconite sand at 92 ft. to the top of the core at 73 ft.

Remarks: Two rather distinct forms of Marginulina are present in the basal Clearwater shales. Marginulina M1-A is more robust, being thick as compared to length, and with somewhat stronger ribs, although the other features of the two forms are the same.

Marginulina M1-A is identical to Marginulina Z-7-54-B Martin from the central part of the Clearwater formation, type section; to Marginulina M22-146-D Stelck from the lower part of the Moosebar formation; and to Wickenden's Marginulina sp.A (1951, Plate 1A, fig. 14-16) from the upper part of the Loon River formation.

Marginulina M1-B

(Plate 2, fig. 3, 4)

This is a more slender form than Marginulina M1-A, and tends to have finer ribs, one specimen having about

eighteen. The relationship between the two forms is probably varietal; Wickenden (1951, Plate 1A, fig. 14-16) figures two similar forms from the Loon River formation as being the same species.

Length of hypotype: .7 mm.
Hypotype locality: as Marginulina M1-A
Hypotype: Univ. of Alberta Pal. Type Coll.
Horizon: as Marginulina M1-A

Genus MILIAMMINA Heron-Allen and Earland, 1930

Miliammina M1-A

(Plate 1, fig. 6)

Test elliptical in outline, usually flattened and distorted in fossilization, hence compressed in cross-section; chambers tubular, but partitioning not usually evident, with four chambers visible on one side and three on the other; sutures rather indistinct, their position emphasized by flattening of the test; wall arenaceous, of fine clear quartz grains set in a matrix of very fine, white, siliceous material, giving a rather smooth but not glassy exterior finish; aperture a round opening at the end of the last chamber on a short but distinct neck; colour white.

Length of Hypotype: .64 mm.
Hypotype locality: Socony-Vacuum Oil Sands Well #27, in section 27-91-10 W4, Alberta, at a depth of 73-81 ft., 28-20 ft. above the base of the Clearwater formation.

Hypotype: Univ. of Alberta Pal. Type Coll.

Horizon: Occasional to common in the basal shales of the Clearwater formation in the Socony-Vacuum Oil Sands Well #27, from the top of the glauconite sand at 92 ft. to the top of the core at 73 ft.

Remarks: This species is very close to Miliammina M1B-62-81 Bahan from the basal Labiche formation; the only difference is that Miliammina M1-A seems to have a more pronounced neck.

Comparison with specimens of Miliammina sproulei Nauss shows that the latter species has a more pronounced neck, is distinctly more elongate rather than elliptical, and has more slender chambers. Nauss' specimens are, however, pyritized and have resisted flattening, and they seem to have recrystallized, obscuring the true nature of the wall material, whereas most of the specimens from the Socony well tend to be distorted in fossilization.

Miliammina manitobensis Wickenden is smaller, more rectangular in outline, and shows partitioning of chambers much better.

Miliammina M8-B

(Plate 1, fig. 1)

Test variable in size and shape, ranging from about .55 mm. to 1.2 mm. in length, usually badly flattened in fossilization; chambers tubular, irregular, distinct, usually four visible on one side and three on the other;

sutures depressed and distinct; wall of very fine, white opaque, arenaceous material, usually with considerable very fine carbonaceous? material adhering to the external surface, imparting a greyish or dirty colour to the test; aperture a round opening at the end of the last chamber, on a short but distinct neck.

Length of hypotype: .85 mm.
Hypotype locality: Socony-Vacuum Oil Sands Well #27, in section 27-91-10 W4, Alberta, at a depth of 117 ft., 16 ft. below the top of the McMurray formation.
Hypotype: Univ. of Alberta Pal. Type Coll.
Horizon: Common to abundant in the Socony-Vacuum Oil Sands Well #27, at a depth of 112-117 ft., 11-16 ft. below the top of the McMurray formation; common to abundant in the A.O.P. Well #77, at a depth of 65-70 to 75-80 ft. in the upper part of the McMurray formation.
Remarks: This form is distinguished by its very large size, the very fine arenaceous character of the wall, and its seemingly thinner wall. The smaller specimens seem identical with Miliammina M1-A found in the overlying basal Clearwater shale, excepting that the latter is more coarsely arenaceous, and the relationship between the two forms is suggested as varietal.

Genus NODOSARIA Lamarck, 1812

Nodosaria obscura Reuss

(Plate 2, fig. 5)

for ref. see: Frizzell,1954, Handbook of Cret. Foram.,p.104.
Test small, tapering in juvenile specimens, becoming more nearly parallel in the adult, circular in cross-section; chambers few, three in hypotype, indistinct; six strong long itudinal ribs running from the base of the test well up onto the terminal face; wall smooth, calcareous, finely perforate; aperture central, terminal, on a small nipple-like protuberance.

Length of hypotype: .35 mm.
Hypotype locality: Socony-Vacuum Oil Sands Well #27, in section 27-91-10 W4, Alberta, at a depth of 73-81 ft., 28-20 ft. above the base of the Clearwater formation
Hypotype: Univ. of Alberta Pal. Type Coll.
Horizon: Very rare, only two specimens being obtained from the basal Clearwater shales in the Socony-Vacuum Oil Sands Well #27, from the top of the glauconite sand at 92 ft. to the top of the core at 73 ft.
Remarks: The hypotype figured here is apparently a juvenile form, the adult specimens being less tapering. Wickenden figures a species of Nodosaria (1951, Plate 1A, fig. 23,24) from the upper part of the Loon River formation which seems to be the same as the Clearwater species.

The Clearwater form is very similar to specimens

referred by Cushman to <u>N. obscura</u> Reuss and <u>N. proboscidea</u> Reuss from the Upper Cretaceous of Texas. However, the Clearwater form differs considerably from the type of <u>N. proboscidea</u> from the Cretaceous of Central Europe in lacking the latter's long terminal neck, and in the Clearwater form's much less distinct sutures and chambers.

Genus PSEUDOGLANDULINA Cushman, 1929.

<u>Pseudoglandulina M1-A</u>

(Plate 2, fig. 15, 16, 17)

Test elongate, circular in cross-section, tapering to sides nearly parallel; chambers few, embracing, distinct, tending to be slightly inflated; sutures distinct, straight, at right angles to the long axis of the test, sutures depressed, especially in later chambers; wall smooth, calcareous, finely perforate, translucent to opaque; aperture terminal, central, finely radiate.

Length of hypotype: .75 mm.
Lengths of figured paratypes: .45 mm. and .55 mm.
Hypotype and figured paratypes locality: Socony-Vacuum Oil Sands Well #27, in section 27-91-10W4, Alberta, at a depth of 73-92 ft., 28-9 ft. above the top of the Clearwater formation.
Hypotype, figured paratypes: Univ. of Alberta Pal. Type Coll.
Horizon: Rare in the basal Clearwater shales of the Socony-Vacuum Oil Sands Well #27, from the top of the glauconite sand at 92 ft. to the top of the core at 73 ft.

Remarks: This species is similar to Pseudoglandulina manifesta Reuss described by Cushman from the Upper Cretaceous of Texas. However, the Clearwater species has a broad smooth base, lacking the pointed initial end of Reuss' type specimen and some of the Texas specimens.

Pseudoglandulina M1-A is the same as Nodosaria Z-7-54-A, Nodosaria Z-7-54-B, and Nodosaria Z-7-48-C described by Martin from the central part of the Clearwater formation, type section; Nodosaria 22-109-A Stelck from the Moosebar formation; and Wickenden's Pseudoglandulina sp. (1951, Plate 1A, fig. 25) from the upper part of the Loon River formation.

Genus SARACENARIA Defrance, 1824.

Saracenaria M1-A

(Plate 2, fig. 18 to 25)

Test small to medium size, close-coiled, involute, later portion gradually becoming inflated and more or less triangular in cross-section; chambers few, from four to seven in the final whorl, gradually increasing in length and breadth, but rarely actually uncoiling; sutures distinct, flush, usually arcuate; periphery sharply rounded but not acute, without a keel; wall calcareous, perforate, hyaline to white opaque; aperture radiate, at the peripheral angle, often on a small projecting cone.

Maximum length of hypotype: .5 mm.

Hypotype and figured paratypes location: Socony-Vacuum Oil

Sands Well #27, in section 27-91-10 W4, Alberta, at a depth of 73-92 ft., 28-9 ft. above the base of the Clearwater formation.

Hypotype and figured paratypes: Univ. of Alberta Pal. Type Coll.

Horizon: Rare to occasional in the basal shales of the Clearwater formation in the Socony-Vacuum Oil Sands Well #27, from the top of the glauconite sand at 92 ft. to the top of the core at 73 ft.

Remarks: This species contains forms which vary from more compressed Lenticulina types to Saracenaria types with a terminal face shaped like an equilateral triangle. Further variation is present in degree of curvature of sutures, number of chambers, and relative sizes of chambers, but only rarely does the test actually begin to uncoil.

There are a number of species figured in the literature similar to the specimens described here as Saracenaria M1-A, one of the closest being Lenticulina navicula d'Orbigny, figured from the Cretaceous of Trinidad by Cushman. However, the Clearwater forms invariably lack the sharp keel of L. navicula.

Locally, forms similar to Saracenaria M1-A have been described by Martin from the central part of the Clearwater formation, type section, and by Stelck from the lower part of the Moosebar formation.

Saracenaria M1-E

(plate 2, fig. 26, 27)

Test medium to large in size, compressed, uncoiling, with the ultimate or penultimate chamber reaching back to embrace the coiled portion, six to ten chambers visible in the last whorl, chambers gradually increasing in size, last two or three uncoiling and becoming slightly inflated and triangular in cross-section; sutures arcuate, distinct, flush or perhaps slightly depressed in the uncoiled portion; periphery narrowly rounded; wall calcareous, perforate, hyaline to white opaque; aperture radiate, at the peripheral angle.

Length of hypotype: .6 mm.
Hypotype location: Socony-Vacuum Oil Sands Well #27, in section 27-91-10 W4, Alberta, at a depth of 73-81 ft., 28-20 ft. above the base of the Clearwater formation.
Hypotype: Univ. of Alberta Pal. Type Coll.
Horizon: Rare to occasional in the basal shales of the Clearwater formation in the Socony-Vacuum Oil Sands well #27, from the top of the glauconite sand at 92 ft. to the top of the core at 73 ft.
Remarks: This form shows variation, particularly in the degree of compression of the test. Gradations from Lenticulina-like specimens to a true Saracenaria type with an inflated, triangle-shaped ultimate chamber are present; the figured specimen is one of the intermediate

forms. The tendency for one of the later chambers to reach back to the coiled portion of the test seems to be the most distinct feature of this species. The test also tends to contract, rather than expand, toward the apertural end.

Similarities between Saracenaria Ml-E and Marginulina cretacea Cushman, and particularly M. siliqua Cushman, are noted, but the Clearwater form is not nearly so compressed and has fewer chambers.

Saracenaria Ml-F

(Plate 2, fig. 28, 29)

Only two specimens of this form were recovered from the basal Clearwater shales in the Socony well. It seems to be a variant of Saracenaria Ml-E, the uncoiled portion of the test being straighter, lacking a tendency to reach back and embrace the coiled portion.

Hypotype locality: as Saracenaria Ml-E

Hypotype: Univ. of Alberta Pal. Type Coll.

Horizon: as Saracenaria Ml-E.

Genus TRITAXIA Reuss, 1860.

Tritaxia Ml-A

(Plate 1, fig. 16, 17)

Test triserial, usually badly flattened in fossilization, and tending to appear biserial; test an elongate, trochoid

spire of about twelve to fifteen chambers, although only the last eight or ten are usually discernable; chambers rapidly expanding, inflated; sutures depressed in later whorls; wall of fine, clear quartz grains set in a white, siliceous cement, giving a rather smooth finish to the exterior surface; aperture terminal, as a round, simple opening, usually at the end of a short but distinct neck; colour white.

Length of hypotype: .73 mm.
Length of figured paratype: .6 mm.
Hypotype and figured paratype locality: Socony-Vacuum Oil Sands Well #27, in section 27-91-10 W4, Alberta, at a depth of 73-81 ft., 28-20 ft. above the base of the Clearwater formation.
Hypotype and paratype: Univ. of Alberta Pal. Type Coll.
Horizon: Occasional to common in the basal shales of the Clearwater formation in the Socony-Vacuum Oil Sands Well #27, from the top of the glauconite sand at 92 ft. to the top of the core at 73 ft.
Remarks: Tritaxia M1-A is identical to Tritaxia Z-5-A Martin from the central and upper part of the Clearwater formation, type section, but has not been found in either the Loon River or Moosebar formations.

Genus TROCHAMMINA Parker and Jones, 1859.

Trochammina M7-A

(Plate 1, fig. 2,3,4,5)

Test small, compressed, periphery sharply rounded and slightly lobate in more flattened specimens; test trochoid with two distinct whorls and obscured primary whorl; spire low and flush with dorsal surface of the ultimate whorl, but made noticeable by its distinctly darker colour; ventral surface concave with small but deep umbilicus; chambers gradually increasing in size, seven to nine visible in ultimate whorl, chambers usually strongly scalloped on ventral side; sutures distinct in ultimate whorl, oblique, slightly arcuate, their positions emphasized by crushing or scalloping of chambers; wall finely arenaceous with much cement, giving a smooth finish to the exterior surface; aperture on ventral side, as a notch on the margin of the ultimate chamber halfway between the umbilicus and the periphery, and extending into the former; colour light to dark brown, with the region of the spire being distincly darker than the outer whorl.

Maximum diameter of hypotype: .4 mm.

Hypotype and figured paratype locality: Socony-Vacuum Oil Sands Well #27, in section 27-91-10 W4, Alberta, at a depth of 112 ft., 11 ft. below the top of the McMurray formation.

Hypotype and figured paratype: Univ. of Alberta Pal. Type Coll.

Horizon: Occasional in the Socony-Vacuum Oil Sands Well #27 at a depth of 107-112 ft., 6-11 ft. below the top of the McMurray formation. The species also occurs occasionally in the A.O.P. Well #77 at a depth of 65-70 to 75-80 ft., in the upper part of the McMurray formation.
Remarks: This species is somewhat similar to Trochammina webbi Stelck and Wall from the Upper Cretaceous Kaskapau formation of the Peace River area. It differs from Trochammina webbi in not being as lobate, in having a smoother exterior finish, and in its much deeper umbilicus and location of aperture.

Genus VERNEUILINOIDES Loeblich and Tappen, 1949.

Verneuilinoides? M7-A

(Plate 1, fig. 13, 14)

Test small to medium in size, slightly tapering, twisted, rounded, triserial but almost always flattened in fossilization; test of about five whorls of three chambers each; chambers trochoid in an ascending spiral, gradually increasing in size, slightly inflated; sutures depressed but generally indistinct owing to crushing or coarsely arenaceous character of the test; wall arenaceous, of clear, subangular quartz grains up to .1 mm. in size, set in a siliceous, reddish-brown cement, amount of cement decreasing in the later whorls; aperture a low arch at the inner margin of the base of the last-formed chamber; colour reddish-brown, often becoming white in the later whorls.

Length of Hypotype: .64 mm.

Length of figured paratype: .47 mm.

Hypotype locality: Socony-Vacuum Oil Sands Well #27, in section 27-91-10 W4, Alberta,at a depth of 112 ft., 11 ft. below the base of the McMurray formation.

Figured paratype locality: Socony-Vacuum Oil Sands Well #27, in section 27-91-10 W4th, Alberta, at a depth of 81-89 ft., 20-12 ft. above the base of the Clearwater formation.

Hypotype: Univ. of Alberta Pal. Type Coll.

Figured paratype: lost.

Horizon: This "species" occurs commonly to abundantly in the Socony-Vacuum Oil Sands Well #27 at a depth of 73-92 ft. in the basal shales of the Clearwater formation, and at a depth of 112-117 ft. in the upper part of the McMurray formation. The "species" is also found in the A.O.P. Well #77 at a depth of 65-70 to 75-80 ft. in the upper part of the McMurray formation.

Remarks: The figured specimen, from which the above description is taken, is somewhat similar to Verneuilinoides cummingensis Nauss from the Cummings member of the Mannville formation, except that the McMurray specimen is more coarsely arenaceous, some of the grains making up the wall being equal to the size of the chambers.

Several different forms, which could be classified under two or three genera, are noted here as belonging

to this "species". The most common of these forms has earlier, additional whorls, each with four to six very small, indistinct chambers, which suddenly expand, developing the adult, triserial whorls. This Eggerella type of test may be the microspheric form of Verneuilinoides? M7-A, but it is much more common than the latter. Another type of test is one which is smaller in size, more rapidly expanding and cone-shaped, and with fewer whorls.

All of these forms, however, seem to have three distinct features in common:

(1) a typical reddish-brown colour, which usually becomes white in the later whorls.

(2) the position of the aperture at the inner margin of the last-formed chamber.

(3) a tendency to be broadly rounded in cross-section when not crushed.

The McMurray specimens are, however, more coarsely arenaceous than those from the overlying Clearwater formation, often incorporating large subangular quartz grains into their tests.

Owing to the poor preservation of material, the writer has not attempted to separate nor figure the various forms present, excepting the Verneuilinoides-like hypotype, and a crushed paratype.

PLATE I

Explanation of Plate 1.

(all magnifications x55)

fig. 1: Miliammina M8-B, from the McMurray formation in the Socony-Vacuum Oil Sands Well #27; hypotype.

fig. 2,3,4,5: Trochammina M7-A, from the McMurray formation in the Socony-Vacuum Oil Sands Well #27; 2, paratype, dorsal view; 3,4,5, hypotype, dorsal, ventral and peripheral views, respectively.

fig. 6: Miliammina M1-A, from the Clearwater formation in the Socony-Vacuum Oil Sands Well #27; hypotype.

fig. 7,8,9: Haplophragmoides M6-B, from the McMurray formation in the Socony-Vacuum Oil Sands Well #27; 7,8, hypotype, side and peripheral views, respectively; 9, paratype, side view.

fig. 10: Haplophragmoides gigas var. minor Nauss, from the Clearwater formation in the Socony-Vacuum Oil Sands Well #27; hypotype.

fig. 11,12: Haplophragmoides M8-C, from the McMurray formation in the Socony-Vacuum Oil Sands Well #27; 11,12, hypotype, side and peripheral views, respectively.

fig. 13,14: Verneuilinoides? M7-A, from the Socony-Vacuum Oil Sands Well #27; 13, hypotype, triserial throughout and showing the large grain size typical of the specimens from the McMurray formation; 14, paratype, a crushed specimen from the Clearwater formation with a suggestion of early, more than triserial whorls.

fig. 15: Haplophragmoides M1-A, from the McMurray formation in the Socony-Vacuum Oil Sands Well #27; hypotype.

fig. 16,17: Tritaxia M1-A, from the Clearwater formation in the Socony-Vacuum Oil Sands Well #27; 16, hypotype; 17, paratype.

fig. 18: Ammobaculites humei Nauss, from the Clearwater formation in the Socony-Vacuum Oil Sands Well #27; hypotype.

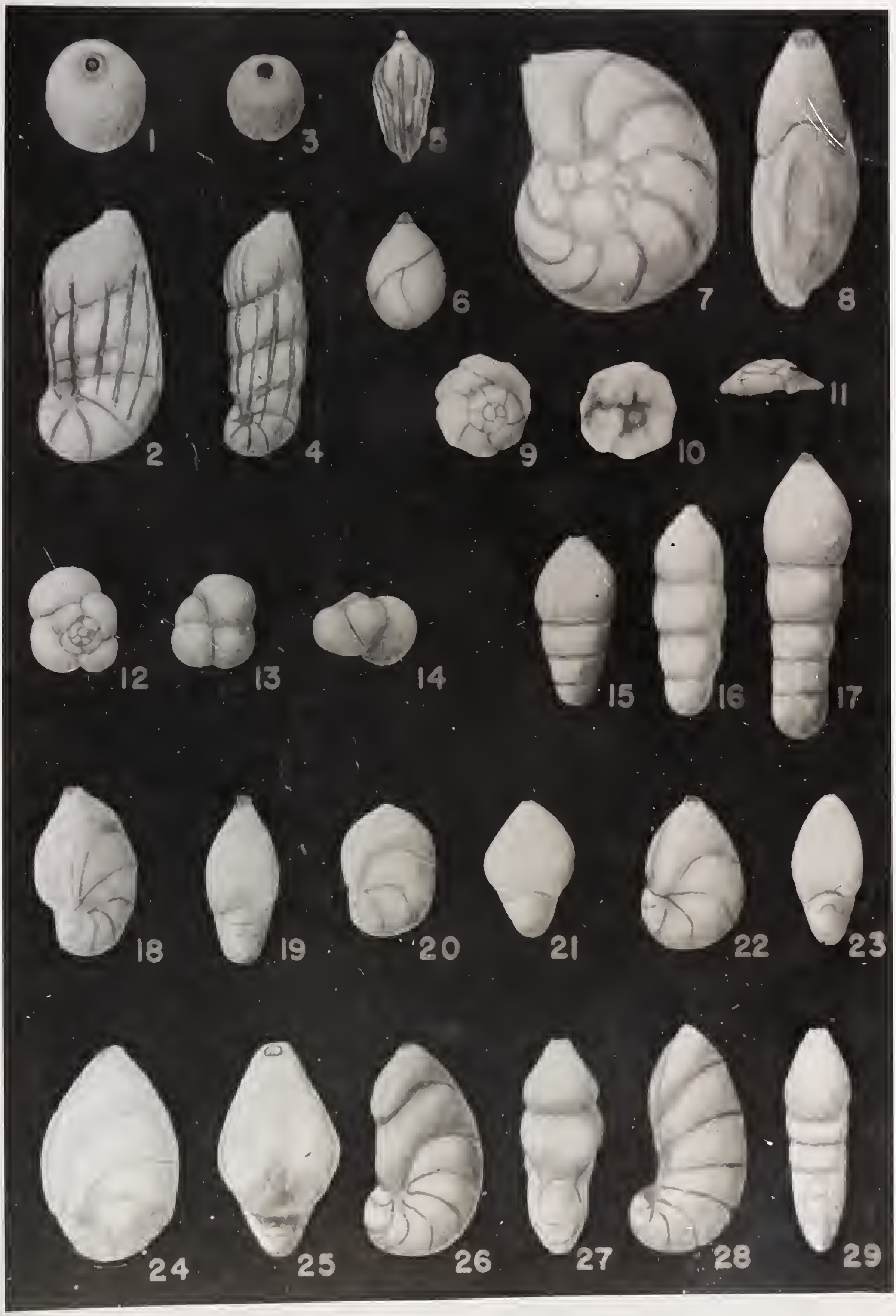


PLATE 2

Explanation of Plate 2.

(all magnifications x55)

fig. 1,2: Marginulina M1-A, from the Clearwater formation in the Socony-Vacuum Oil Sands Well #27; 1,2, hypotype, apertural and side views, respectively.

fig. 3,4: Marginulina M1-B, from the Clearwater formation in the Socony-Vacuum Oil Sands Well #27; 3,4, hypotype, apertural and side views, respectively.

fig. 5: Nodosaria obscura Reuss, from the Clearwater formation in the Socony-Vacuum Oil Sands Well #27; hypotype.

fig. 6: Globulina lacrima Reuss, from the Clearwater formation in the Socony-Vacuum Oil Sands Well #27; hypotype.

fig. 7,8: Lenticulina M1-A, from the Clearwater formation in the Socony-Vacuum Oil Sands Well #27; 7,8, hypotype, side and peripheral views, respectively.

fig. 9,10,11: Discorbis M1-A, from the Clearwater formation in the Socony-Vacuum Oil Sands Well #27; 9,10,11, hypotype, dorsal, ventral and side views, respectively.

fig. 12,13,14: Eponides M1-A, from the Clearwater formation in the Socony-Vacuum Oil Sands Well #27; 12,13,14, hypotype, dorsal, ventral and side views, respectively.

fig. 15,16,17: Pseudoglandulina M1-A, from the Clearwater formation in the Socony-Vacuum Oil Sands Well #27; 15,16, paratypes; 17, hypotype.

fig. 18 to 25: Saracenaria M1-A, from the Clearwater formation in the Socony-Vacuum Oil Sands Well #27; 18,19, hypotype, oblique and peripheral views, respectively; 20,21, paratype, side and peripheral views, respectively; 22,23, paratype, side and peripheral views, respectively; ~~22,23, paratype, side and peripheral views, respectively;~~ 24,25, paratype, side and peripheral views, respectively.

fig. 26,27: Saracenaria M1-E, from the Clearwater formation in the Socony-Vacuum Oil Sands Well #27; 26,27, hypotype, side and peripheral views, respectively.

fig. 28,29: Saracenaria M1-F, from the Clearwater formation in the Socony-Vacuum Oil Sands Well #27; 28,29, hypotype, side and peripheral views, respectively.

SAMPLE NUMBER	1A	1	2	3	5	6	7	8	9	10	11	12	13	14	15	17	18	19	20	21	22	23	24	25	26	27	28	29	31	32	33
Ammobaculites humei		95	24	5																											
Haplophragmoides gigas minor		c	c	c																											
Haplophragmoides M1-A		c	c	c																										p	
Haplophragmoides M6-B					2	14																		2	20	3?				p	
Haplophragmoides M8-C							3	6																		2					
Miliammina M1-A		37	15	4																										5	
Miliammina M8-B							24	110																	27	132					
Tritaxia M1-A		30	12	7																										5	
Trochammina M7-A						4	17																	1	9	12					
Verneuilinoides? M7-A		135	94	c			28	3																	117	54				5	
Discorbis M1-A	2	2																													
Eponides M1-A	7	13	8																												
Globulina lacrima	10	7	2	1																											
Lenticulina M1-A	5	3	1																												
Marginulina M1-A	12	8	3	1																											
Marginulina M1-B	?	7																													
Nodosaria obscura		1	1																												
Pseudoglandulina M1-A	3	4																													
Saracenaria M1-A	29	24	6	3																											
Saracenaria M1-E	9	8	1																												
Saracenaria M1-F	1	1																													
Cytheridea sp.	p	p	p																												
ostracodes indet.																	4	11	37		7										
unident. aren. objects									4?			1		3			10	60	20												
"spores"									3	8	5	6	11	40	10	20	7	11	2	5	3										

"c" indicates common
"p" indicates present

TABLE 1 : POPULATION COUNTS OF INDIVIDUAL SAMPLES

(Sample locations in appendix)

CHAPTER FOUR

General statement

The study of the petrology of the McMurray formation is limited in this thesis to the study of the non-opaque heavy minerals of the sand fraction; however, certain statements on the general lithology of the formation can be made.

The sands of the McMurray formation consist of from 90% to 95% or more of subround to angular quartz, and can, therefore, be classified under the "quartz-muscovite sandstone" category of Dapples, et. al. (1948, p.1931), or as "orthoquartzites" by Pettijohn's (1949) definition.

Examination of the "light" fraction of eleven samples from outcrop sections and the Socony-Vacuum Oil Sands Well #27 show a minor but persistent amount of feldspar (orthoclase) present in all samples. The average quartz-feldspar content of the eleven samples is 96% quartz-4% feldspar, with the maximum amount of feldspar being 8% and the minimum amount being 2%.

Muscovite is a very conspicuous mineral in the McMurray sands, and most hand specimens taken from outcrops along the Athabasca River show white, glittering flakes of the mineral along the bedding planes. No data on the amount of muscovite is available, and the amount would vary with regard to locality and average grain size of the unit sampled, but certainly enough of the mineral is present in

those sands examined by the writer to justify calling them quartz-muscovite sands.

It is interesting to note that rock or chert fragments are either absent or very rare in the McMurray sands, and Wickenden (1951,p.43) calls attention to this fact in comparing the sands of the McMurray formation with other Lower Cretaceous sandstones of Alberta, which presumably had their source to the west in the Cordilleran area.

In summary, the sands of the McMurray formation consist mainly of quartz and minor amounts of orthoclase, muscovite, and heavy minerals. The strata may become argillaceous, particularly near the top of the formation, but do not in the type section area approach either the composition of an arkose or subgraywacke as defined by modern petrologists.

Heavy minerals

Previous data on the heavy minerals of the McMurray formation has been confined to casual comments, excepting Kupsch' (1954) paper on pockets of bituminous sands in glacial tills of Northwest Saskatchewan. Kupsch pointed out how the McMurray sands may be differentiated from glacial sands using heavy minerals, although the writer disagrees with his identification of chlorite and andalusite, which are probably chloritoid and apatite, respectively.

Non-opaque heavy minerals were examined by the writer from eighteen samples of the McMurray sands, and the relative percentages of these minerals present in each sample are shown in Table 2.

The opaque heavy minerals include the usual assemblage of "leucoxene", hematite, limonite, pyrite, and ilmenite or magnetite, but their precise identification is uncertain and they have little genetic significance. As the opaques sometimes form as high as 80% or 90% of the heavy-mineral suites, their abundance would obscure the true percentage distribution of the non-opaques, which have more genetic significance. Consequently, the opaques were ignored in making heavy mineral counts.

A brief description of the non-opaque heavy mineral species follows:

Tourmaline is the most prominent non-opaque heavy mineral present, forming an average 47% of the non-opaque heavies. The mineral occurs in a number of shapes and colours but, although a much more refined classification of tourmaline could be made on the basis of colour and types of inclusions (Krynine, 1946), the writer intends the following "classification" to serve only a very general descriptive purpose. These, then, are the main types, based on colour, of tourmaline present in the McMurray formation:

(1) Very pale brown to distinct brown or greenish-brown subhedral prisms or fragments of larger prisms, pleochroic to dark brown or black. Common.

(2) Pale pink to almost reddish subhedral prisms or fragments of larger prisms, pleochroic to greenish-black or black. Less common than type (1). Only the occasional pink grain is pleochroic to blue.

(3) Blue, pleochroic to darker blue. Rare.

(4) Near-basal sections which show maximum absorption make up an average of about 40% of the tourmaline present in 3 samples so investigated. Brownish-green basal sections are most common, followed by black, almost opaque sections. Orange or light brown basal sections are much less common, and blue ones are rare.

The greenish-brown or near-opaque sections may be confused with biotite or hornblende, but they invariably give a slightly off-centre uniaxial figure when tested.

The occurrence and significance of tourmaline as a detrital mineral has been summarized by Krynine (1946) who outlined five main sources of sedimentary tourmaline:

(1) granitic tourmaline.

(2) pegmatitic tourmaline.

(3) tourmaline from metamorphic terranes.

(4) sedimentary authigenic tourmaline, occurring as overgrowths on detrital tourmaline grains.

(5) reworked tourmaline from older sediments.

The first four classes include the various varieties of primary tourmaline which, upon erosion of the parent rock, appear in sediments as first-cycle detrital grains. While authigenic tourmaline is easily recognized, granitic, pegmatitic, and metamorphic tourmaline must be differentiated on the basis of colour and inclusions. Reworked tourmaline is derived from pre-existing sedimentary rocks, and is,

therefore, a second-cycle mineral, although the original source must have been from igneous or metamorphic rocks, except for the authigenic variety.

The tourmaline from the McMurray formation has helped considerably in deriving the nature of the source area of the bituminous sands, for which purpose the mineral has been divided into two groups:

(1) well-rounded basal or prism sections, presumed to be second-cycle and derived from pre-existing sedimentary rocks.

(2) subangular or angular tourmaline, presumed to be first-cycle and derived from an igneous-metamorphic terrane.

Just how well-rounded a tourmaline grain must be to justify calling it second-cycle is a matter of personal prejudice. Inasmuch as the mineral is very resistant to abrasion and chemical reaction, tourmaline can be reworked several times over, appearing as fourth or fifth-cycle grains. At what stage of reworking tourmaline may become sufficiently rounded to be recognized as coming from sediments, as opposed to igneous or metamorphic rocks, would also depend on the duration of abrasion prior to deposition.

The average of counts from four samples indicates that at least 30% of the tourmaline grains are sufficiently rounded to be classified as second-cycle. The remaining 70% of the grains which vary from small idiomorphic

crystals or angular fragments of larger crystals to sub-angular or sub-rounded grains is thought to be first-cycle, coming from the same source that provided the garnet, kyanite, staurolite, etc.

Authigenic tourmaline occurring as overgrowths on pre-existing tourmaline grains is rare in the McMurray formation. Only the sand from the quarry at Bitumount showed any appreciable amount (6%), while four other samples had one grain apiece (trace). The overgrowths tend to be well abraided, occurring on well-rounded pale brown or pinkish grains, and have undoubtedly passed through at least one cycle of erosion.

Zircon is present in all samples examined, making up from 1% to 41% of the non-opaque heavy minerals. The mineral is almost always colourless, only the occasional yellow or purple grain being observed, and small euhedra or sub-angular zircons are more common than the well-rounded (presumably second-cycle) variety.

A rather peculiar feature of as much as one-third of the zircon present in some samples is the presence of a reddish, opaque film clinging to the grains, partially obscuring them and making identification difficult. This film was not observed on any of the other non-opaques, and the writer does not know its origin.

Garnet makes up an average of 9% of the non-opaque heavy minerals. It occurs as colourless, often shard-like

fragments, and is remarkably fresh in appearance. Pink garnet is extremely rare, only one or two grains being observed in the 18 samples examined.

For some reason, garnet is the dominant non-opaque heavy mineral in the glauconite sand which, as already pointed out, was deposited in a marine environment. Moreover, the garnet in the glauconite sand tends to be pitted and etched, and is associated with a rather large amount of apatite (11%). The explanation for the rather large concentration of these two minerals in this sample is unknown to the writer.

Staurolite is present in all samples examined, making up an average of 11% of the non-opaque heavy minerals. The mineral is almost colourless or pale golden yellow, pleochroic to deep yellow, and often shows "swiss-cheese structure" typical of staurolite. The grains are generally angular to sub-angular, but the larger ones often show signs of abrasion, tending to be somewhat rounded. The occasional grain shows "hacksaw" terminations (Pettijohn, 1949, p. 491) where the 010 cleavage is at right angles to the tube of the microscope.

Kyanite occurs typically as clear, lathe-like grains, and is present in most of the samples in small but persistent amounts, except in one sample where it makes up 31% of the non-opaque heavies. Kyanite and staurolite

are derived from medium to high rank metamorphic rocks, and are considered to be first-cycle minerals.

Chloritoid. A mineral identified as chloritoid forms an average of 12% of the non-opaque heavy minerals. As chloritoid is not commonly reported as a detrital, a brief description of the mineral as found in the McMurray formation is given here. It occurs as angular, micaceous flakes, and in two general but gradational varieties:

(1) as greenish-blue, non-pleochroic flakes full of tiny, lineated, colourless inclusions; or marked by swarms of round or oval, black, opaque inclusions which are sometimes so abundant that the mineral is nearly opaque.

    Under crossed-nicols this variety presents a cryptocrystalline or "wispish" appearance, and will not give an interference figure.

(2) About one-quarter of the chloritoid present occurs as inclusion-free flakes, markedly pleochroic from deep blue to olive green, or less commonly from light blue to almost colourless.

    Under crossed-nicols this variety shows very low interference colours (grey or "ultra-blue"), and usually yields a biaxial positive figure. The isogyres are rather "fuzzy" and show strong dispersion.

    This pleochroic variety grades into the non-pleochroic, inclusion-ridden variety so that no definite line between the two types can be drawn.

The chloritoid from the McMurray formation almost exactly matches the description given by Milner (1929, p.158). The mineral could, however be confused with certain varieties of "chlorite" except that the index of chloritoid is much higher (1.71 to 1.75). The genetic significance of the two minerals is quite different, "chlorite" being an alteration product after various ferromagnesian minerals, while chloritoid is a primary, metamorphic mineral forming in the place of staurolite under certain conditions.

Rutile is a very minor constituent of the heavy mineral fraction. Generally two or three grains of the mineral were observed in each sample, occurring as angular to well-rounded, deep brown or reddish grains.

Apatite. With the exception of the glauconite sand, apatite forms 2% or less of the non-opaque heavy minerals. It is found as colourless, generally sub-angular grains, with a slight orange tinge around the edges. The mineral is further characterized by its low birefringence and the uniaxial negative figure of the basal sections.

Amphiboles are conspicuous only by their absence. Only a few grains of hornblende were observed in a sample from the basal beds of the formation near the mouth of Steepbank River.

Others. This category includes the few grains of epidote, zoisite, sphene and sillimanite that were observed in the

18 samples examined. Because of their rare occurance, these minerals have little genetic significance.

Unidentified includes the several grains in each sample that the writer could not identify because of the altered condition of the grain or the lack of diagnostic characteristics.

Evaluation of the heavy mineral data

The lithological samples from the McMurray formation from both the Socony-Vacuum core and outcrops give a very consistent qualitative picture of the non-opaque heavy mineral assemblage present in the formation. It must be admitted that certain other aspects of the distribution of heavy minerals within the formation could be investigated: variation in heavy mineral composition with regard to size fraction of the sands, and rounding and shapes of the various mineral species present are two such studies that could be made. But these are problems in themselves and would not help solve the problem of source of the McMurray sands. The writer considers that enough data has been compiled to make an intelligent interpretation of the nature of the source area, and to dispel certain erroneous ideas about the nature of this source area.

It is obvious in the light of petrological evidence that igneous, metamorphic and sedimentary rocks have contributed to the sediments of the McMurray formation. As the McMurray formation has been correlated in this thesis with marine shales in the lower part of the Loon River

SAMPLE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Av.
Tourmaline	18	50	55	48	54	54	60	60	58	54	47	55	54	50	48	28	10	40	47
Zircon	3	9	5	9	1	6	4	8	8	13	8	3	9	21	11	15	41	20	11
Rutile		t			t			.1		t	3	1	1	1	2	1	3	1	1
Garnet	52	14	4	6	3	2	8	7	3	4	5	6	4	8	6	18		8	9
Staurolite	5	8	12	11	3	5	12	8	11	15	9	9	14	9	18	14	12	21	11
Kyanite	4	6	6	3	3	4	5	3	6	8	3	4	2	8	4	12	31	5	6.5
Chloritoid	5	10	17	18	35	27	6	9	12	5	25	21	14	2	10	3		2	12
Apatite	11	2		2	1	1	1	1	t	1			1		t	2	t	1	1
Amphibole																2			
Others	t			t				t			t				t	2			
Unidentified	2	1	1	2	1	1	3	2	2	t	1	1	1	2	1	2	2	1	1.5

RELATIVE PERCENTAGES OF HEAVY MINERALS WITHIN THE MCMURRAY SANDS

TABLE 2

formation, the only possible source for the bituminous sands would be to the east, on what is now referred to as the Canadian Shield. The absence of chert and rock fragments in the McMurray sands, which are a common feature of those Cretaceous sandstones which received their sediments from the Cordilleran area to the west, further supports this contention.

Sproule (1951, p.10) suggests that the late Precambrian or early Palaeozoic Athabasca sandstone, which supposedly covers a large area of Northwestern Saskatchewan, contributed a large part of the sands to the McMurray formation. Mawdsley (1954) investigated heavy minerals from three samples of the Athabasca sandstone, finding only small amounts of well-rounded tourmaline, zircon and rutile present. Tourmaline grains from one of the three samples carried large authigenic overgrowths which certainly would have survived reworking. One third of the tourmaline from a sample of recent sands along the Clearwater River, which drains part of the area underlain by the Athabasca sandstone, also has very noticeable authigenic overgrowths, and yet such tourmaline is rare in those samples of the McMurray sands investigated by the writer. Not enough data is available, particularly with regard to the Athabasca sandstone, to be dogmatic about whether or not the Athabasca sandstone did contribute to the McMurray sediments, but it can be stated with certainty that the formation did not contribute the major part of the McMurray sediments.

The heavy mineral assemblage from the McMurray formation can be divided into two groups:

(1) first cycle minerals derived from an igneous-metamorphic terrane. This group includes all of the staurolite, kyanite, chloritoid, garnet, apatite, and an estimated two-thirds of the tourmaline and zircon.

(2) second-cycle minerals derived from pre-existing sedimentary rocks. This group would include some of the tourmaline and zircon, and possibly rutile.

The igneous and metamorphic rocks were almost certainly those of the Precambrian terranes of the Canadian Shield, while the sedimentary source rocks were probably Precambrian or early Palaeozoic sandstones, similar to the McMurray sands in that they were also made up largely of pure quartz rather than quartz and chert. The distribution of early Palaeozoic strata on what is now the Canadian Shield in McMurray time is largely a matter of conjecture, but the Shield was not covered completely as has been suggested. Furthermore, the distance of transport of the McMurray sands from the source area to the site of deposition is not known, and the writer rejects the possibility that quantitative textural studies of the McMurray sands would solve this problem. The nature of the source rocks can therefore be ascertained, but how far to the east they lay can only be guessed at.

The absence of plagioclase, biotite, amphiboles and

pyroxenes in the McMurray sands, and which certainly must have been present in the original source area, suggests that the source area was of low relief and had undergone rather intense weathering prior to erosion and redeposition as the McMurray sediments. As the McMurray formation rests on the Devonian limestones of the Waterways formation, that part of the Shield which contributed to the McMurray sediments was emergent during Carboniferous, Permian, Triassic, Jurassic, and most of Lower Cretaceous times. There is no suggestion that seas of those ages ever reached the lower Athabasca River area, much less further east. As a result, weathering of the source area over such a long period would remove most of the feldspar along with the amphiboles, pyroxenes and biotite. This insinuates that kyanite, staurolite, chloritoid, garnet and apatite survived weathering processes, and were redeposited along with the more stable quartz, tourmaline and zircon to form the McMurray sands.

Conclusion

In summary, deposition of the McMurray sediments began with the initial downwarp which brought the lower Loon River Sea into Northern Alberta. Source of the McMurray sediments was to the east, from a well-weathered area of low relief, underlain by igneous, metamorphic and sedimentary rocks. Sedimentation was rapid at first, allowing the McMurray strata to be deposited as a delta-like

wedge on the eastern margin of the sea; however, as rate of subsidence overcame rate of deposition, the late Loon River or Clearwater sea spread further east into Saskatchewan, drowning the delta and bringing McMurray sedimentation to a close.

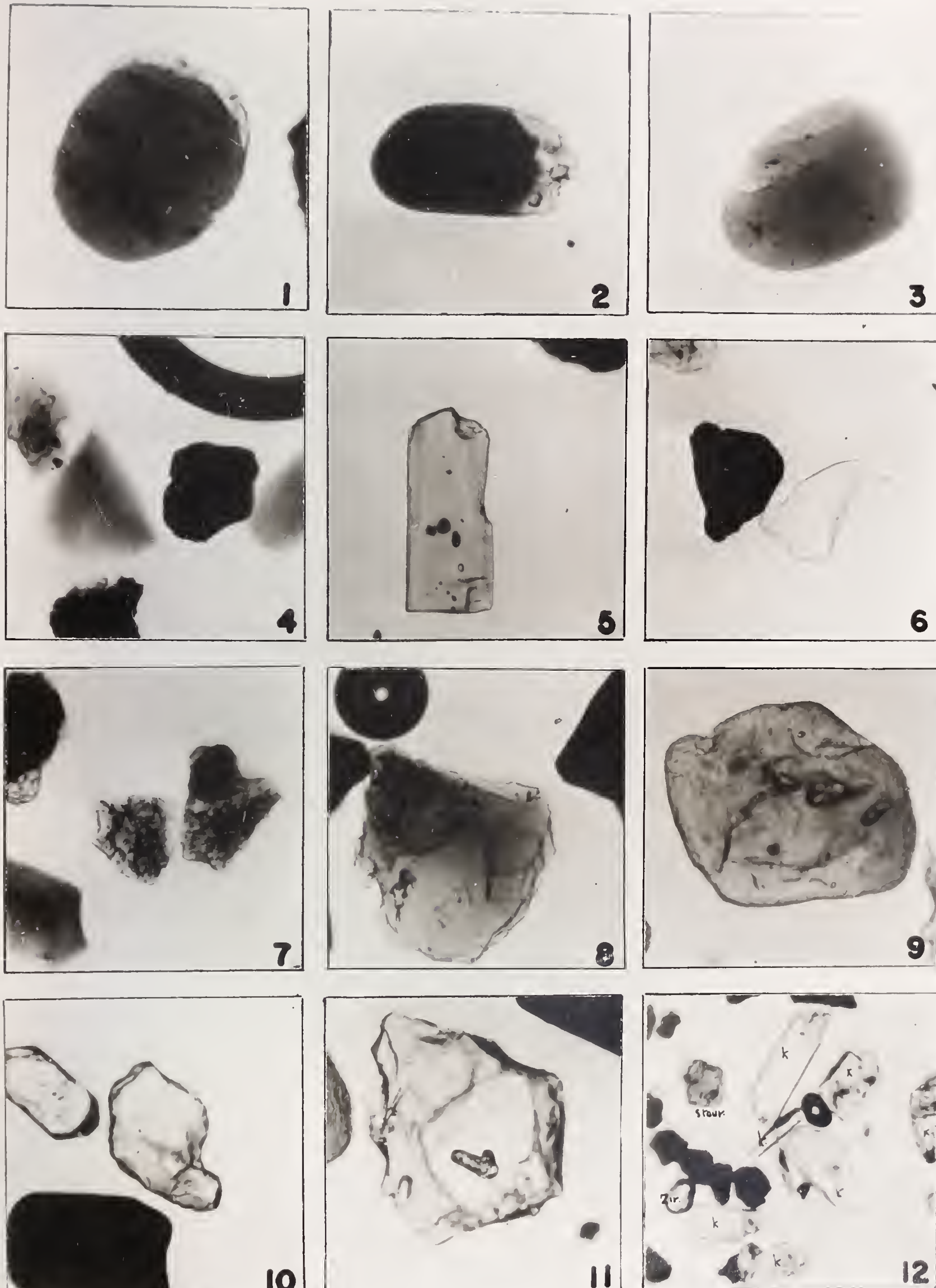


PLATE 3

Explanation of Plate 3.

fig. 1: pink tourmaline with abraided overgrowth, from McMurray sand from the quarry at Bitumount.

fig. 2: light brown tourmaline with overgrowth, from McMurray sand from the quarry at Bitumount.

fig. 3: well-rounded, coffee-brown basal section of tourmaline, from McMurray sand from the quarry at Bitumount.

fig. 4: angular, brownish-green basal section of tourmaline, from McMurray sand in the Socony-Vacuum well.

fig. 5: pale brown, subhedral tourmaline prism, from McMurray sand from the quarry at Bitumount.

fig. 6: apatite, from the glauconite sand in the Socony-Vacuum well.

fig. 7: two grains of inclusion-ridden chloritoid, from McMurray sand in the Socony-Vacuum well.

fig. 8: pleochroic, inclusion-free chloritoid, from non-bituminous McMurray sand on the Clearwater River.

fig. 9: rounded staurolite, from non-bituminous McMurray sand on the Clearwater River.

fig.10: garnet and euhedral zircon, from basal McMurray sand on the Athabasca River near the mouth of Steepbank River.

fig.11: garnet, from non-bituminous McMurray sand on the Clearwater River.

fig.12: kyanite, from McMurray sand on Athabasca River between Ft. MacKay and Bitumount. Low power.

REFERENCES CITED

Badgley, P.C., (1952): Notes on the subsurface stratigraphy and oil and gas geology of the Lower Cretaceous Series in Central Alberta; Geol. Surv. Canada, Paper 52-11.

Bahan, W.G., (1951): Microfauna of the Joli Fou formation in North-Central Alberta; unpublished M.Sc. thesis, Dept. of Geology, Univ. of Alberta.

Bell, Robt., (1884): Report on part of the basin of the Athabasca River, Northwest Territories; Geol. and Nat. Hist. Survey and Museum of Canada, Rept. of Progress 1882-83-84, Pt. C.

Dapples, E.C., Krumbein, W.C., and Sloss, L.L., (1948): Tectonic review of lithologic associations; Bull. Amer. Assoc. Pet. Geol., Vol. 32, No. 10, pp. 1924-1947.

Galliher, E.W., (1935): Geology of glauconite; Bull. Amer. Assoc. Pet. Geol., Vol. 19, pp. 1569-1601.

Gordon, A.G., (1932): The anatomical structure of Mesozoic plants from the bituminous sands of the McMurray formation; unpublished M.Sc. thesis, Dept. of Botany, Univ. of Alberta.

Hume, G.S., (1947): Results and significance of drilling operations in the Athabasca bituminous sands; Transactions, Can. Inst. Min. and Metall., Vol. L, 1947, pp. 298-333.

Krynine, P.D., (1946): The tourmaline group in sediments; Jour. Geol., Vol. LIV, No. 2, pp. 65-87.

Kupsch, W.O., (1954): Bituminous sands in till of the Peter Pond Lake area, Saskatchewan; Sask. Geol. Surv., Rept. No. 12.

Loranger, D.M., (1951): Useful Blairmore microfossil zone in Central and Southern Alberta, Canada; Bull. Amer. Assoc. Pet. Geol., Vol. 35, No. 11, pp. 2348-2367.

Martin, L.J., (1954) Clearwater shale foraminifera, Athabasca River, Alberta; unpublished M.Sc. thesis, Dept. of Geology, Univ. of Alberta.

Mawdsley, J.C., (1954): Mineralogic study of the Athabasca sandstone: typewritten report, Dept. of Geology, Univ. of Alberta.

McConnell, R.G., (1893): report on a portion of the District of Athabasca etc.; Geol. Surv. Canada, Ann. Rept. 1890-91, Vol. V, Pt. 1, Sec. D.

McLearn, F.H., (1917): Athabasca River section; Geol. Surv. Canada, Summ. Rept. 1916, pp. 145-151.

____________, (1931): The Gastroplites and other Lower Cretaceous faunas etc.; Trans. Royal Soc. Canada, Vol. XXV, Sec. IV.

____________, (1932): Problems of the Lower Cretaceous of the Canadian Interior; Trans. Royal Soc. Canada, Vol. XXVI, Sec. IV.

____________, (1933): Pelecypods of the Lower Cretaceous Clearwater formation, northern Alberta; Trans. Royal Soc. Canada, Vol. XXVII, Sec. IV.

____________, (1945): Revision of the Lower Cretaceous of the western interior of Canada; Geol. Surv. Canada, Paper 44-17 (Sec. edit.)

Milner, H.B., (1929): Sedimentary Petrography; Thos. Murby and Co., London, 1929, sec. edit.

Nauss, A.W., (1945): Cretaceous stratigraphy of the Vermilion area, Alberta, Canada; Bull. Amer. Assoc. Pet. Geol., Vol. 29, No. 11, pp. 1605-1629.

____________, (1947): Cretaceous fossils of the Vermilion area, Alberta; Jour. Pal., Vol. 21, No. 4, pp. 329-343.

Norris, A.W., (1951): Some cutinized microfossils from western Canada; unpublished M.Sc. thesis, Dept. of Geology, Univ. of Alberta.

Pettijohn, F.J., (1949): Sedimentary Rocks; Harper and Bros., New York, 1949.

Phleger, F.B., (1954): Ecology of foraminifera and associated micro-organisms from Mississippi Sound and environs; Bull. Amer. Assoc. Pet. Geol., Vol. 32, No. 10.

Russell, L.S., (1932): Mollusca from the McMurray formation of northern Alberta; Trans. Royal Soc. Canada, Vol. XXVI, Sec. IV.

Sproule, J.C., (1951): The McMurray formation in its relation to oil occurrence; Proceedings, Athabasca Oil Sands Conference (symposium), Govt. of Alberta, Edmonton, 1951.

Stelck, C.R., (1950): Cenomanian-Albian foraminifera of western Canada; unpublished Ph.D. thesis, Stanford University.

Warren, P.S., and Stelck, C.R., (1950): Succession of Devonian faunas in western Canada; Trans. Royal Soc. Canada, Vol. XLIV, Pt. IV.

Wickenden, R.T.D., (1949): Some Cretaceous sections along the Athabasca River etc.; Geol. Surv. Canada, Paper 49-15.

_______________, (1951A): Some Lower Cretaceous sections on Peace River below the mouth of the Smoky River, Alberta; Geol. Surv. Canada, Paper 51-16.

_______________, (1951B): Regional correlation of the Lower Cretaceous formations of the McMurray oil-sand area; Proceedings, Athabasca Oil Sands Conference (symposium); Govt. of Alberta, Edmonton, 1951.

Workman, L.E., et al., (1954): Lower Cretaceous of the Peace River region; Western Canada Sedimentary Basin, Rutherford Memorial Volume, Amer. Assoc. Pet. Geol., 1954.

Trollope, F.H., (1951): A lower microfauna from the Loon River formation, Alberta; unpublished M.Sc. thesis, Dept. of Geology, Univ. of Alberta.

APPENDIX

Location of micropalaeontological samples

(1) from the core of the Socony-Vacuum Oil Sands Well #27; location, section 27-91-10 W4, Alberta.

M1A - 73 to 92 ft., includes calcareous foraminifera and ostracodes picked from three intervals in the Clearwater shale, from a depth of 73 to 92 ft.

M1 - 73 to 81 ft., consists of six shale samples combined, from the Clearwater shale, from a depth of 73 to 81 ft.

M2 - 81 to 89 ft., consists of six shale samples combined, from the Clearwater shale, from a depth of 81 to 89 ft.

M3 - 90 ft., dark grey, glauconitic Clearwater shale, just above the gradational contact with the glauconite sand.

M5 - 102 ft., black, sandy shale, about one foot below the gradational contact of the glauconite sand, i.e. one foot below the top of the McMurray formation.

M6 - 106-107 ft., black shale, 5-6 ft. below the top of the McMurray formation.

M7 - 112 ft., black shale, 11 ft. below the top of the McMurray formation.

M8 - 117 ft., black shale, 16 ft. below the top of the McMurray formation.

M9 - 119 ft., light grey shale, 18 ft. below the top of the McMurray formation.

M10 - 132 ft., grey shale, 31 ft. below the top of the McMurray formation.

M11 - 139 ft., grey shale, 38 ft. below the top of the McMurray formation.

M12 - 153 ft., grey shale, 52 ft. below the top of the McMurray formation.

M13 - 173 ft., grey shale, 72 ft. below the top of the McMurray formation.

M14 - 185 ft., grey shale, 84 ft. below the top of the McMurray formation.

M15 - 193 st., grey shale, 92 ft. below the top of the McMurray formation.

M17 - 227 ft., grey shale, 126 ft. below the top of the McMurray formation.

M18 - 234 ft., grey shale, 133 ft. below the top of the McMurray formation.

M19 - 242 ft., grey shale, 141 ft. below the top of the McMurray formation.

M20 - 248 ft., grey shale, 147 ft. below the top of the McMurray formation.

M21 - 260 ft., grey shale, 159 ft. below the top of the McMurray formation.

M22 - 279 ft., grey shale, 178 ft. below the top of the McMurray formation.

M23 - 286 ft., grey shale, 185 ft. below the top of the McMurray formation.

M24 - 291 ft., grey shale, 190 ft. below the top of the McMurray formation.

(2) from the core of the Athabasca Oilsands Project Well #77; location, section 29-94-11 W4, Alberta.

Driller's log of this well is as follows:

0 - 35 ft., drift.
35 - 57 ft., black, glauconitic clay (Clearwater ?).
57 - 85 ft., mostly black clay, some poor oilsand.
85 - 85.6 ft. clay ironstone.
85.6 - 115 ft., poor to fair oilsand, black clay interbeds.
115 - 153 ft., very good oilsand, few black clay interbeds.
153 - 155 ft., grey clay.
155 - 181 ft., excellent oilsand.
181 - 189 ft., fair oilsand, dark clay interfingers.
189 - 200 ft., good oilsand.
200 - 202 ft., grey clay.
202 - 205 ft., bitumen impreg. clay ironstone.
205 - 215 ft., grey limey shale, limestone.

The exact top of the McMurray formation in this well is somewhat uncertain, but is above the depth of 57 ft.

The locations of the samples in this core are at the following depths:

M25 - 55 to 60 ft.

M26 - 65 to 70 ft.

M27 - 75 to 80 ft.

M28 - 85 to 90 ft.

M29 - 95 to 100 ft.

(3) Outcrop Samples.

M31 - grey clay at the base of the McMurray formation on the Athabasca River, about twelve miles north of McMurray.

M32 - slumped, weathered grey shale and greenish sand, overlying bituminous sands on Hangingstone River.

M33 - grey clay and bituminous sand laminae from near the base of the McMurray formation on Hangingstone River.

Location of petrological samples

(1) from the core of the Socony-Vacuum Oil Sands Well #27; location, section 27-91-10 W4, Alberta.

L1 - glauconitic sandstone at a depth of 95-96 ft. within the core.

L2 - bituminous sand at 115 ft.

L3 - bituminous sand at 132 ft.

L4 - bituminous sand at 152 ft.

L5 - bituminous sand at 175 ft.

L6 - bituminous sand at 194 ft.

L7 - bituminous sand at 217 ft.

L8 - bituminous sand at 235 ft.

L9 - bituminous sand at 252 ft.

L10 - bituminous sand at 282 ft.

(2) Outcrop samples.

L11 - bituminous sand from the upper part of the McMurray formation on Hangingstone River.

L12 - bituminous sand near the base of the McMurray formation on Hangingstone River.

L13 - bituminous sand from the quarry at Bitumount.

L14 - bituminous sand from the upper part of the McMurray formation on the Athabasca River, about twelve miles north of McMurray.

L15 - bituminous sand from the upper part of the McMurray formation near the mouth of Steepbank River.

L16 - bituminous sand at the base of the McMurray formation near the mouth of Steepbank River.

L17 - unimpregnated sand between MacKay and McMurray.

L18 - unimpregnated sand from the Clearwater River, near the mouth of High Hill River.